AMERICAN SOCIETY
for
TESTING MATERIALS

Reg. U. S. Pat. Off.

PROCEEDINGS
of the
FORTY-SEVENTH ANNUAL MEETING
Held at New York, N. Y.
June 26–30, 1944

VOLUME 44

COMMITTEE REPORTS
TECHNICAL PAPERS

Published by the
AMERICAN SOCIETY FOR TESTING MATERIALS
260 S. Broad St., Philadelphia 2, Pa.

Nothing contained in any publication of the American Society for Testing Materials is to be construed as granting any right, by implication or otherwise, for manufacture, sale, or use in connection with any method, apparatus, or product covered by Letters Patent, nor as insuring anyone against liability for infringement of Letters Patent.

The Society is not responsible, as a body, for the statements and opinions advanced in this publication

COPYRIGHT, 1945
BY THE
AMERICAN SOCIETY FOR TESTING MATERIALS
Printed in Baltimore, U. S. A.
April, 1945

CONTENTS

PROCEEDINGS

PAGE

Summary of Proceedings of the Forty-seventh Annual Meeting........ 1

The Art of Being a Materials Engineer: Annual Address by the President—Dean Harvey........ 30

Annual Report of the Executive Committee........ 39

COMMITTEE REPORTS

Ferrous Metals

Report of Committee A-1 on Steel........ 63

Appendix. Recommendations Affecting Standards for Steel........ 73

Report of Committee A-2 on Wrought Iron........ 83

Report of Committee A-3 on Cast Iron........ 85

Report of Committee A-5 on Corrosion of Iron and Steel........ 87

Report of Subcommittee VIII on Field Tests of Metallic Coatings........ 92

Appendix. Proposed Specifications for Lead-Alloy (Hot-Dip) Coated Steel Sheets........ 110

Report of Committee A-6 on Magnetic Properties........ 114

Report on Round-Robin Core Loss Testing at High Flux Densities........ 120

Report of Committee A-7 on Malleable-Iron Castings........ 124

Report of Committee A-10 on Iron-Chromium, Iron-Chromium-Nickel and Related Alloys........ 126

Cooperative Study of Effect of Rate of Strain on the Tensile Properties of Stainless Sheets........ 133

Report of the Research Committee on Fatigue of Metals........ 136

Appendix. Third Progress Report on the Effect of Size of Specimen on Fatigue Strength of Three Types of Steel—Prepared by D. Morkovin and H. F. Moore........ 137

Discussion........ 156

Report of Joint Research Committee on Effect of Temperature on the Properties of Metals........ 159

Appendix I. Study of Effects of Variables on the Creep Resistance of Steels—Prepared by H. C. Cross and W. Simmons........ 161

Appendix II. Correlation of Short- and Long-Time Elevated Temperature Test Methods........ 186

Discussion........ 215

Report of Joint Committee on Filler Metal........ 216

Non-Ferrous Metals

Report of Committee B-1 on Copper and Copper-Alloy Wires for Electrical Conductors........ 218

Report of Committee B-2 on Non-Ferrous Metals and Alloys........ 220

Report of Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys........ 222

Report of Subcommittee VI on Atmospheric Corrosion Tests of Non-Ferrous Metals and Alloys........ 224

Report of Committee B-4 on Electrical-Heating, Electrical-Resistance and Electric-Furnace Alloys........ 240

Report of Committee B-5 on Copper and Copper Alloys, Cast and Wrought........ 243

Appendix. Recommendations Affecting Standards for Copper and Copper Alloys, Cast and Wrought........ 250

PAGE

- Report of Committee B-6 on Die-Cast Metals and Alloys 261
- Report of Committee B-7 on Light Metals and Alloys, Cast and Wrought 266
  - Appendix. Recommendations Affecting Standards for Light Metals and Alloys, Cast and Wrought 270
- Report of Committee B-8 on Electrodeposited Metallic Coatings 278
  - Report of Subcommittee II on Performance Tests 280
- Report of Committee B-9 on Metal Powders and Metal Powder Products 292

Cementitious, Ceramic, Concrete, and Masonry Materials

- Report of Committee C-1 on Cement 294
  - Report of Working Committee on Additions 299
    - Appendix. The Data on Darex AEA 300
  - Appendix I. Report on Cooperative Studies of Proposed Method of Test for Air Content of Portland-Cement Mortar 306
  - Appendix II. Proposed Method of Chemical Analysis for Darex Air-Entraining Agent in Portland Cement 311
  - Appendix III. Summary of Proposed Revisions in Methods of Chemical Analysis of Portland Cement 313
- Report of Committee C-7 on Lime 317
  - Report of Special Subcommittee on Use of the Autoclave for Testing Lime 320
- Report of Committee C-8 on Refractories 331
- Report of Committee C-9 on Concrete and Concrete Aggregates 336
  - Appendix. Volumetric Method for Determining the Air Content of Freshly Mixed Concrete—Prepared by J. C. Pearson 343
    - Discussion 351
- Report of Committee C-12 on Mortars for Unit Masonry 352
- Report of Committee C-14 on Glass and Glass Products 354
- Report of Committee C-15 on Manufactured Masonry Units 356
- Report of Committee C-16 on Thermal Insulating Materials 358

Miscellaneous Materials

- Report of Committee D-1 on Paint, Varnish, Lacquer, and Related Products 362
- Report of Committee D-2 on Petroleum Products and Lubricants 368
  - Appendix I. Conversion Tables for Petroleum Oils of Metric Tons in Vacuo to Long and Short Tons in Air 381
  - Appendix II. Oil Measurement 384
  - Appendix III. Proposed Method of Analysis of Petroleum Sulfonates 386
  - Appendix IV. Proposed Method of Test for Potential Gum in Aviation Gasoline 393
- Report of Sectional Committee Z11 on Petroleum Products and Lubricants 398
- Report of Committee D-3 on Gaseous Fuels 399
- Report of Committee D-4 on Road and Paving Materials 401
- Report of Committee D-5 on Coal and Coke 406
- Report of Committee D-6 on Paper and Paper Products 411
- Report of Committee D-7 on Timber 415
- Report of Committee D-8 on Bituminous Waterproofing and Roofing Materials 417
- Report of Committee D-9 on Electrical Insulating Materials 422
  - Appendix I. Recommendations Affecting Standards for Electrical Insulating Materials 432
  - Appendix II. Investigation of Test Procedures for Dielectric Strength of Liquid Insulation 439
  - Appendix III. Proposed Methods of Test for Gas Content of Insulating Oil 450
- Report of Sectional Committee C59 on Electrical Insulating Materials 457
- Report of Committee D-11 on Rubber Products 459
- Report of Committee D-12 on Soaps and Other Detergents 470
- Report of Committee D-13 on Textile Materials 474
  - Appendix. Recommendations Affecting Standards for Textile Materials 481
- Report of Committee D-16 on Industrial Aromatic Hydrocarbons 490
- Report of Committee D-17 on Naval Stores 492
  - Appendix. Proposed Method of Test for Unsaponifiable Matter in Rosin 495
- Report of Committee D-18 on Soils for Engineering Purposes 497
- Report of Committee D-19 on Water for Industrial Uses 500
- Joint Research Committee on Boiler Feedwater Studies 504
- Report of Committee D-20 on Plastics 505
  - Appendix. Proposed Revisions in Standards for Plastics 510

Miscellaneous Subjects

PAGE
Report of Committee E-1 on Methods of Testing 515
Report of Committee E-2 on Spectrographic Analysis 519
Report of Committee E-3 on Chemical Analysis of Metals 521
Report of Committee E-4 on Metallography 523
  Appendix. Proposed Revisions in Tentative Methods of Preparation of Metallographic Specimens 525
Report of Committee E-8 on Nomenclature and Definitions 531
Report of Committee E-10 on Standards 533

TECHNICAL PAPERS

Edgar Marburg Lecture

Textile Fibers—An Engineering Approach to Their Properties and Utilization: Nineteenth Edgar Marburg Lecture—Harold DeWitt Smith 543

Metals

The Technical Cohesive Strength of Some Steels and Light Alloys at Low Temperatures—D. J. McAdam, Jr., R. W. Mebs, and G. W. Geil 593
  Discussion 624
Evolution of Test Specimen for Non-Ferrous Castings—A. J. Smith 625
  Discussion 636
An Alternate Immersion Test for Aluminum-Copper Alloys—Robert B. Mears, C. J. Walton, and G. G. Eldredge 639
Basic Requirements in the Standardization of the Salt Spray Corrosion Test—Leo J. Waldron 654
  Discussion 663
Micro-Deformation Under Tension and Compression Loads of Thin Aluminum Alloy Sheets for Aircraft Construction—Georges Welter 665
  Discussion 682
Short-Time Tests of Solders and Soldered Joints—J. A. Kies and W. F. Roeser 691
  Discussion 707
A Numerical Rating Method for the Routine Metallographic Examination of Commercial Magnesium Alloys—P. F. George (see ASTM BULLETIN, *No. 129, August, 1944, p. 35; Discussion, p. 43).*
Quantitative Spectrographic Analysis of Copper Alloys—R. A. Wolfe and Emile J. Jemal (see ASTM BULLETIN, *No. 129, August, 1944, p. 45; Discussion, p. 52).*

Symposium on Analytical Colorimetry and Photometry

Opening Remarks by G. E. F. Lundell 709
Introduction—Trends in Analytical Chemistry—B. L. Clarke 710
Colorimetric Analysis and Beer's Law—J. L. Hague 712
Filter Photometers—A. E. Ruehle 718
Glass Photometric Filters—O. A. Gage 720
Spectrophotometers—Kasson S. Gibson 725
The Chemistry in Colorimetry—M. G. Mellon 733
Bibliography of Photoelectric Spectrophotometric Methods of Analysis for Inorganic Ions—J. W. Stillman 740
Colorimetric Determination of Silicon in Aluminum Alloys—Joseph J. Stumm 749
Colorimetric Methods for the Analysis of Magnesium-Base Alloys—V. A. Stenger 754
Colorimetric Methods for the Analysis of Copper-Base Alloys and Refined Lead—C. Zischkau 762
Colorimetric Methods for the Analysis of Ferrous Alloys—Arba Thomas 769

Round-Table Discussion on Centrifugal Castings

Summary of Proceedings—N. L. Mochel 779

Cement, Concrete, Lime, Refractories, Masonry Materials

Volumetric Method for Determining the Air Content of Freshly Mixed Concrete—J. C. Pearson, Appendix, Report of Committee C-9 on Concrete and Concrete Aggregates (see p. 343; Discussion, p. 351).

PAGE

The Effects of Certain Variations in Consistency and Curing Conditions on the Compressive Strengths of Cement-Lime Mortars—G. J. Fink.......... 780
Discussion.......... 788
The Reaction of Vinsol Resin as it Affects the Air Entrainment of Portland-Cement Concrete—Charles E. Wuerpel and Albert Weiner (see ASTM BULLETIN, *No. 130, October, 1944, p. 41; Discussion, p. 43).*
Comparative Tests of 52 Brands of Portland Cement from 15 Countries—Eugene V. Barrett.......... 793
Discussion.......... 802
A Comparison of Results of Sieving Procedures in Soundness Tests on Maine Sands—Andrew Adams and Horace A. Pratt.......... 806
Application of Fly Ash for Lean Concrete Mixes—Harry A. Frederick.......... 810
Discussion.......... 819
Entrained Air—Its Effect on the Constituents of Portland Cement Concretes—Henry L. Kennedy.......... 821
Discussion.......... 831
Precision Indices for Compression Tests of Companion Concrete Cylinders—S. P. Wing, Walter H. Price, and Clemeunt T. Douglass.......... 839
Discussion.......... 852
The Measurement of Concrete Strength by Embedded Pull-Out Bars—Bailey Tremper.......... 880
Some Properties of Concrete Under Sustained Combined Stresses—C. Martin Duke and Harmer E. Davis.......... 888
Tests Comparing the Modulus of Elasticity of Portland Cement Concrete as Determined by the Dynamic (Sonic) and Compression (Secant at 1000 psi.) Methods—T. E. Stanton (see ASTM BULLETIN, *No. 131, December, 1944, p. 17; Discussion, p. 20).*
The Effect of Discontinuities on the Natural Frequency of Beams—Philip G. Kirmser. 897

Miscellaneous

Measurement of Fading Resistance of Camouflage Type Finishes by Accelerated Weathering—J. W. Iliff and L. B. Darrall.......... 905
The Interpretation of Visual Rusting Standards—W. F. Singleton.......... 910
Fatigue Tests on Compressed and Impregnated Laminated Wood—Albert G. H. Dietz and Henry Grinsfelder (see ASTM BULLETIN, *No. 129, August, 1944, p. 31; Discussion, p. 34).*
Factors Influencing the Breaking Strength of Army and Navy Fabrics—Werner von Bergen, John C. Hintermaier, and Eric Ullman.......... 916
Short-Time Static Tests and Creep Tests of a Paper Laminated Plastic—W. N. Findley and W. J. Worley.......... 949
Discussion.......... 967
Indentation Hardness of Plastics—Ladislav Boor.......... 969
Discussion.......... 992
Impact Testing of Plastics—II. Factors Which Influence the Energy Absorbed by the Specimen—David Telfair and H. K. Nason.......... 993
Discussion.......... 1006
Flow of Thermosetting Plastics at Elevated Temperatures—John Delmonte and E. Watkins.......... 1009
Discussion.......... 1016
Characteristics of the Tuckerman Strain Gage—Bruce L. Wilson.......... 1017
Factors Affecting Hardness Relationships in the Range 50 to 250 Brinnell—Robert H. Heyer.......... 1027
Discussion.......... 1046

Round-Table Discussion on Organizing the Classification of Industrial Waters

Introduction—W. C. Schroeder.......... 1051
Typical Water Analyses for Classification with Reference to Industrial Use—W. D. Collins.......... 1057

PAGE
The Use of Selected Waters in Pulp and Paper Manufacture—Lewis B. Miller..... 1061
Treatment of Various Types of Waters for Operating Pressures Above 400 psi.—R. E. Hall..... 1069
Classification of Feedwater for Boilers Operating Between 100–400 psi.—J. A. Holmes 1078
General Discussion..... 1082
Summary of Proceedings of the Cincinnati Spring Meeting—Symposium on the Applications of Synthetic Rubbers..... 1095

Subject Index..... 1097
Author Index..... 1123

SUMMARY OF PROCEEDINGS OF THE FORTY-SEVENTH ANNUAL MEETING

NEW YORK, N. Y., JUNE 26–30, 1944

The following Summary records the action taken by the Society at the Annual Meeting on the Recommendations Affecting Standards and Tentative Standards appearing in the annual reports of the standing committees. In the individual committee reports attention is called through an editorial footnote to any modifications of the recommendations or where the recommendations of the committee were not approved. In all other instances it is to be understood that the recommendations were approved as submitted by the committee. The new and revised standards and tentative standards are published in the 1944 Book of A.S.T.M. Standards, Parts I, II, and III. Except as noted, the reports and paper appear in this volume.

This summary of the Forty-seventh Annual Meeting of the American Society for Testing Materials, held at The Waldorf-Astoria, New York, N. Y., June 26–30, 1944, is a record of the transactions of the meeting including the actions taken on the various recommendations submitted by the standing committees. In all, 16 sessions were held.

The registered attendance of the meeting is as follows: Members present or represented, 1185; committee members, 368; guests, 510; total, 2063.

The Proceedings are set forth session by session. There were 58 reports and 52 formal papers presented. The record with respect to each has been briefed, the recommendations in the reports having been grouped so as to cover the acceptance of material for publication as tentative, such as new specifications, methods of test, revisions of tentative standards and proposed revisions of existing standards, and as a separate group, the approval of matters that were referred to letter ballot of the Society, comprising the adoption of tentative standards as standard and the adoption of revisions of standards. Accordingly, wherever the action is reported as "adopted as standard," or "adopted as standard, revisions in" it is understood that this indicates approval of the annual meeting for reference to letter ballot of the Society. The various recommendations so recorded are included in the Society letter ballot.[1] The actions designated as "accepted as tentative" or "accepted as tentative, revisions in," are self evident as indicating acceptance by the Society at the Annual Meeting for publication as tentative.

While all of the items on the program are recorded under the particular session in which they were presented, for convenience in locating actions with respect to any particular report, the accompanying list is presented of all the reports together with the page reference where the action thereon is recorded.

---

[1] The letter ballot on recommendations affecting standards, distributed to the Society membership, was canvassed on September 15, 1944, and all actions were approved.

LOCATION OF ACTIONS ON COMMITTEE REPORTS

PAGE

Committee:

Executive Committee 14
A-1 on Steel 15
A-2 on Wrought Iron 20
A-3 on Cast Iron 20
A-5 on Corrosion of Iron and Steel 19
A-6 on Magnetic Properties 20
A-7 on Malleable-Iron Castings 20
A-10 on Iron-Chromium, Iron-Chromium-Nickel and Related Alloys 19

B-1 on Copper and Copper-Alloy Wires for Electrical Conductors 24
B-2 on Non-Ferrous Metals and Alloys 27
B-3 on Corrosion of Non-Ferrous Metals and Alloys 24
B-4 on Electrical-Heating, Electrical-Resistance and Electric-Furnace Alloys 24
B-5 on Copper and Copper Alloys, Cast and Wrought 23
B-6 on Die-Cast Metals and Alloys 28
B-7 on Light Metals and Alloys, Cast and Wrought 27
B-8 on Electrodeposited Metallic Coatings 28
B-9 on Metal Powders and Metal Powder Products 25

C-1 on Cement 21
C-7 on Lime 20
C-8 on Refractories 22
C-9 on Concrete and Concrete Aggregates 25
C-12 on Mortars for Unit Masonry 21
C-14 on Glass and Glass Products 5
C-15 on Manufactured Masonry Units 21
C-16 on Thermal Insulating Materials 21

D-1 on Paint, Varnish, Lacquer, and Related Products 12
D-2 on Petroleum Products and Lubricants 6
D-3 on Gaseous Fuels 6
D-4 on Road and Paving Materials 8
D-5 on Coal and Coke 6
D-6 on Paper and Paper Products 11
D-7 Timber 4
D-8 on Bituminous Waterproofing and Roofing Materials 8
D-9 on Electrical Insulating Materials 5
D-10 on Shipping Containers 4
D-11 on Rubber Products 5
D-12 on Soaps and Other Detergents 11
D-13 on Textile Materials 10
D-16 on Industrial Aromatic Hydrocarbons 12
D-17 on Naval Stores 11
D-19 on Water for Industrial Uses 3
D-20 on Plastics 4

E-1 on Methods of Testing 3
E-2 on Spectrographic Analysis 3
E-3 on Chemical Analysis of Metals 3
E-4 on Metallography 20
E-7 on Radiographic Testing 3
E-8 on Nomenclature and Definitions 3
E-9 on Research 13
E-10 on Standards 13

Round-Table Discussion on Organizing the Classification of Industrial Waters 3
Round-Table Discussion on Centrifugal Castings 6
Symposium on Analytical Colorimetry and Photometry 9
Research Committee on Fatigue of Metals 3
Joint Research Committee on Effect of Temperature on the Properties of Metals 20
Joint Research Committee on Boiler Feedwater Studies 3
Joint A.W.S.-A.S.T.M. Committee on Filler Metal 19

FIRST SESSION—WATER

TUESDAY, JUNE 27, 2 P.M.

SESSION CO-CHAIRMEN: PRESIDENT DEAN HARVEY; W. C. SCHROEDER

President Dean Harvey extended a very cordial welcome to the members and guests in opening the Forty-seventh Annual Meeting of the Society. He stated that the Society had a very successful year as evidenced by the progress and accomplishments in its standardization and research activities which are covered in detail in the many reports and papers to be presented at this annual meeting. He stated that from the expected attendance, the increased number of committee meetings, and the number of interesting technical sessions this promised to be the largest and most successful meeting held by the Society.

Committee D-19 on Water for Industrial Uses:

Report presented by Max Hecht, chairman.

Joint Research Committee on Boiler Feedwater Studies:

Report, not preprinted, presented from manuscript by J. B. Romer, secretary.

Round-Table Discussion on Organizing the Classification of Industrial Waters:

This Round-Table Discussion was introduced by W. C. Schroeder, and the following papers were then presented:

Typical Water Analyses for Classification with Reference to Industrial Use—W. D. Collins, presented by the author.

The Use of Selected Waters in Pulp and Paper Manufacture—Lewis B. Miller, W. H. & L. D. Betz, presented from manuscript by Mr. Miller.

Treatment of Various Types of Waters for Operating Pressures Above 400 psi.—R. E. Hall, presented from manuscript by the author.

Classification of Feedwater for Boilers Operating Between 100–400 psi.—J. A. Holmes, presented from manuscript by the author.

SECOND SESSION—FATIGUE, METHODS OF TESTING

TUESDAY, JUNE 27, 3 P.M.

SESSION CHAIRMAN: VICE-PRESIDENT, J. R. TOWNSEND

Research Committee on Fatigue of Metals:

Report, not preprinted, presented from manuscript by H. F. Moore, chairman, including a further progress report on the studies of effect of size of specimen on fatigue strength.

Committee E-1 on Methods of Testing:

Report presented by H. F. Moore, vice-chairman, and the following actions taken:[2]

Adopted as Standard:

Spec. for Air Chamber Thermometer and for Tung Oil Thermometer, prescribed in Tentative Spec. for A.S.T.M. Thermometers (E 1–44 T).

Adopted as Standard, Revisions in

Spec. for A.S.T.M. Thermometer (E 1 – 42), to include explanatory notes on periodic checking of changes of bulb volume of glass thermometers and on ice point determinations of glass thermometers.

Committee E-7 on Radiographic Testing:

Report, not preprinted, presented from manuscript by Lars Thomassen.

Committee E-8 on Nomenclature and Definitions:

Report presented, in the absence of the chairman, by the chair.

Committee E-3 on Chemical Analysis of Metals:

Report, not preprinted, presented from manuscript by G. E. F. Lundell, chairman.

Committee E-2 on Spectrographic Analysis:

Report, not preprinted, presented from manuscript by H. V. Churchill, chairman.

---

[2] This recommendation, not preprinted, was accepted by unanimous consent subject to favorable letter ballot of Committee E-1, which ballot has been favorable and the results are given in the report of the committee, see p. 515.

Papers:

The following papers were presented:

Characteristics of the Tuckerman Strain Gage—Bruce L. Wilson, presented by the author.

Factors Affecting Hardness Relationships in the Range 50 to 250 Brinell—Robert H. Heyer, presented by the author.

Quantitative Spectrographic Analysis of Copper Alloys[3]—R. A. Wolfe and Emile J. Jemal, presented from manuscript by Mr. Wolfe.

THIRD SESSION—TIMBER, PLASTICS, ELECTRICAL INSULATING MATERIALS, RUBBER

TUESDAY, JUNE 27, 2 P.M.

SESSION CHAIRMAN: MYRON PARK DAVIS

Committee D-7 on Timber:

Report presented by Hermann von Schrenk, chairman.

Committee D-10 on Shipping Containers:

The activities of this committee were reported upon informally by L. J. Markwardt.

Committee D-20 on Plastics:

Report presented by L. W. A. Meyer, secretary, and the following actions taken:

Accepted as Tentative:

Spec. for Cellulose Acetate Plastic Sheets
Spec. for Ethyl Cellulose Molding Compounds
Spec. for Methacrylate Molding Compounds
Spec. for Nylon Injection Molding Compound
Flexural Test of Plastics
Test for Rockwell Hardness of Plastics and Electrical Insulating Materials, submitted jointly with Committee D-9.
Test for Luminous Reflectance and Transmission Characteristics and Color of Plastic Materials
Test for Specific Gravity of Plastics
Test for Short-Time Stability at Elevated Temperatures of Plastics Containing Chlorine
Rec. Practice for Determining Permanent Effect of Heat on Plastics
Rec. Practice for Accelerated Weathering of Plastics Using S-1 Bulb and Fog Chamber
Rec. Practice for Molding Impact Specimens of General Purpose Phenolic Material

Accepted as Tentative, Revisions in:

Spec. for Nonrigid Vinyl Butyral Plastics (D 745 – 43 T)
Spec. for Vinylidene Chloride Molding Compounds (D 729 – 44 T)
Spec. for Cellulose Acetate Molding Compounds (D 706 – 43 T)
Spec. for Cellulose Acetate Butyrate Molding Compounds (D 707 – 43 T)
Spec. for Cellulose Nitrate (Pyroxylin) Plastic Sheets, Rods, and Tubes (D 701 – 43 T)
Spec. for Melamine-Formaldehyde Molding Compounds (D 704 – 43 T)
Spec. for Nonrigid Vinyl Chloride-Acetate Plastics (D 742 – 43 T)
Spec. for Nonrigid Ethyl Cellulose Plastics (D 743 – 43 T)
Spec. for Nonrigid Vinyl Chloride Plastics (D 744 – 43 T),[4] with changes in Sections 2 and 6 (*c*) and in Tables I and II providing for an additional type with two grades, and revisions in certain requirements for the present types and grades.
Test for Brittleness of Nonrigid Plastics (D 746 – 43 T)
Test for Distortion Under Heat of Molded Electrical Insulating Materials (D 648–41 T), subject to concurren by Committee D-9.
Test for Measuring Relative Mobility of Thermosetting Molding Powder (D 731 – 43 T)
Test for Tensile Properties of Plastics (D 638 – 42 T)
Test for Haze of Transparent Plastics by Photoelectric Cell (D 672 – 42 T)
Methods of Conditioning Plastics and Electrical Insulating Materials for Testing (D 618 – 41 T)
Test for Deformation of Plastics Under Load at Elevated Temperatures (D 621 – 43)

Adopted as Standard:

Test for Flammability of Plastics Over 0.050 in. in Thickness (D 635 – 41 T)
Test for Mar Resistance of Plastics (D 673 – 42 T)
Test for Coefficient of Linear Thermal Expansion of Plastics (D 696 – 42 T)

It was announced that the recommendation in the preprinted report covering revisions in the Tentative Specifications for Laminated Thermosetting Materials (D 709 – 43 T) had been withdrawn by the committee.

---

[3] Published in ASTM BULLETIN, No. 129, August 1944, p. 45.

[4] This recommendation, not preprinted, was accepted by unanimous consent, subject to favorable letter ballot of Committee D-20, which ballot has been favorable and the results are given in the report of the committee, see p. 506.

Committee D-9 on Electrical Insulating Materials:

Report presented by W. A. Zinzow, secretary, and the following actions taken:

Accepted as Tentative:

Spec. for Orange Shellac and Other Indian Lacs for Electrical Insulation
Test for Rockwell Hardness of Plastics and Electrical Insulating Materials, submitted jointly with Committee D-20.

Accepted as Tentative, Revisions in:

Test for Power Factor and Dielectric Constant of Electrical Insulating Materials (D 150 - 42 T)
Sampling and Testing Untreated Paper Used in Electrical Insulation (D 202 - 41 T)
Spec. for Phenolic Laminated Sheet for Radio Applications (D 467 - 40 T)
Conditioning Plastics and Electrical Insulating Materials for Testing (D 618 - 41 T)
Testing Electrical Insulating Oils (D 117 - 43)
Testing Sheet and Plate Materials Used in Electrical Insulation (D 229 - 43)
Testing Laminated Tubes Used in Electrical Insulation (D 348 - 42)
Testing Laminated Round Rods Used in Electrical Insulation (D 349 - 42)
Test for Grading and Classification of Natural Mica (D 351 - 38)

Adopted as Standard:

Test for Saponification Number of Petroleum Products by Color-Indicator Titration (D 94 - 43 T)
Test for Dielectric Strength of Electrical Insulating Materials at Commercial Power Frequencies (D 149 - 40 T)
Testing Solid Filling and Treating Compounds Used for Electrical Insulation (D 176 - 42 T)
Testing Glass Spool Insulators (D 550 - 41 T)
Test for Punching Quality of Phenolic Laminated Sheets (D 617 - 41 T)
Test for Product Uniformity of Phenolic Laminated Sheets (D 634 - 41 T)
Testing Steatite Used as Electrical Insulation (D 667 - 42 T)
Measuring Dimensions of Rigid Tubes Used in Electrical Insulation (D 668 - 42 T)

It was announced that the recommendation in the report for adoption as standard of the Tentative Methods of Test for Sludge Formation in Mineral Transformer Oil (D 670 - 42 T) had been withdrawn by the committee.

Adopted as Standard, Revisions in:

Testing Electrical Porcelain (D 116 - 42)
Testing Shellac Used for Electrical Insulation (D 411 - 42)

Withdrawal of Standard:

Test for Comparing Thermal Conductivities of Solid Electrical Insulating Materials (D 325 - 31 T)

Accepted for Publication as Information Only:

Test for Gas Content of Insulating Oil

Sectional Committee C59 on Electrical Insulating Materials:

Report, not preprinted, presented from manuscript by H. L. Curtis, chairman.

Committee D-11 on Rubber Products:

Report presented by S. Collier, acting chairman, and the following actions taken:

Accepted as Tentative:

Test for Stiffening of Vulcanized Elastomers at Low Temperatures
Spec. for Cellular Rubber Products

Accepted as Tentative, Revisions in:

Testing Sponge Rubber Products (D 552 - 43 T)
Testing Automotive Hydraulic Brake Hose (D 571 - 40 T)
Testing Automotive Air Brake and Vacuum Brake Hose (D 622 - 41 T)
Test for Indentation of Rubber by Means of the Durometer (D 676 - 42 T)
Spec. for Chloroprene Sheath Compound for Electrical Insulated Cords and Cables (D 752 - 43 T)
Spec. for Chloroprene Sheath Compound for Electrical Insulated Cords and Cables Where Extreme Abrasion Resistance is Not Required (D 753 - 43 T)
Spec. for Insulated Wire and Cable: Performance Synthetic Rubber Compound (D 755 - 43 T)

Adopted as Standard:

Test for Resistance to Light Checking and Cracking of Rubber Compounds (D 518 - 38 T)
Test for Tear Resistance of Vulcanized Rubber (D 624 - 41 T)
Sampling and Testing Rubber Latex (D 640 - 41 T),[5] with revisions adapting them to testing both natural and synthetic rubber latices.

Committee C-14 on Glass and Glass Products:

Report presented by title.

---

[5] This recommendation, not preprinted, was accepted by unanimous consent, subject to favorable letter ballot of Committee D-11, which ballot has been favorable and the results are given in the report of the committee, see p. 464.

Papers:

The following papers were presented:

Fatigue Tests on Compressed and Impregnated Laminated Wood[6]—Albert G. H. Dietz and Henry Grinsfelder, presented by Mr. Grinsfelder.

Short-Time Static Tests and Creep Tests of a Paper Laminated Plastic—W. N. Findley and W. J. Worley, presented by Mr. Findley.

Indentation Hardness of Plastics—Ladislav Boor, presented by the author.

Impact Testing of Plastics—II. Factors Which Influence the Energy Absorbed by the Specimen—Davis Telfair and H. K. Nason, presented from manuscript by Mr. Telfair.

Flow of Thermosetting Plastics at Elevated Temperatures—John Delmonte and E. Watkins, presented by Mr. Delmonte.

FOURTH SESSION—ROUND-TABLE DISCUSSION ON CENTRIFUGAL CASTINGS

HELD JOINTLY WITH THE AMERICAN FOUNDRYMEN'S ASSOCIATION

WEDNESDAY, JUNE 28, 9:30 A.M.

SESSION CHAIRMAN: N. L. MOCHEL

The Round-Table Discussion was of an informal nature, completely off the record, and was participated in by a number of leading producers and consumers, who discussed production technique and problems in determining the properties of centrifugal castings, types of specimens, and related matters. A brief statement covering this discussion appears on page 779.

FIFTH SESSION—PETROLEUM PRODUCTS, COAL AND COKE, FUELS, BITUMINOUS MATERIALS

WEDNESDAY, JUNE 28, 9:30 A.M.

SESSION CHAIRMAN: E. O. RHODES

Committee D-5 on Coal and Coke:

Report presented by A. C. Fieldner, chairman, and the following actions taken:

Adopted as Standard, Revisions in:

Method for Designating the Size of Coal from Its Screen Analysis (D 431 - 38)

Methods of Laboratory Sampling and Analysis of Coal and Coke (D 271 - 43)

Adopted as Standard:

Def. of the Terms Gross Calorific Value and Net Calorific Value of Fuels (D 407 - 35 T), as revised, with a minor change in the note substituting "appropriate" for the word "correct" in the last sentence.

Editorial Changes Accepted in:

Method of Tumbler Test for Coke (D 294 - 29)

Methods of Laboratory Sampling and Analysis of Coal and Cole (D 271 - 43)

A motion picture film on the subject "Sampling of Solid Fuels" was then shown through the courtesy of the Pennsylvania State College, Fuel Technology Extension. The film illustrated the application of A.S.T.M. methods for sampling coal and was introduced by A. W. Gauger.

Committee D-3 on Gaseous Fuels:

Report presented by A. W. Gauger, chairman

Committee D-2 on Petroleum Products and Lubricants:

Report presented by T. G. Delbridge, vice-chairman, and the following actions taken:

Accepted as Tentative, Revisions in:

Test for Aniline Point of Petroleum Products (D 611 - 43 T)

Test for Consistency of Lubricating Greases and Petrolatum (D 217 - 38 T), with a further revision[7] of the method separating the procedures for grease and petrolatum and incorporating minor changes.

Test for Knock Characteristics of Aviation Fuels (D 614 - 43 T), with the following additional revisions:[7]

Section 5 (n).—Change title to read "Fuel-Air Ratio for Maximum Thermal-Plug Temperature."

Section 5 (p).—Change lines 8 to 11 to read: ". . . until equal thermal-plug temperatures are obtained for the two fuels in a mean of three alternate comparisons, within a tolerance of 1.0 F. (0.6 C)." Also in lines 13 and 14 change "maximum knock mixture" to "the fuel-air ratio for maximum knock."

---

[6] Published in ASTM BULLETIN, No. 129, August, 1944, p. 31

[7] These recommendations, not preprinted, were accepted by unanimous consent, subject to favorable letter ballot of Committee D-2, which ballot has been favorable and the results are given in the report of the committee, see p. 379

Section 7 (*a*).—In lines 12 and 13, change "mixture adjustment" to "readjustment of fuel-air ratio."

Section 7 (*b*).—Change title to "Adjustment of Fuel-Air Ratio." In item (*2*), line 3 change "air-fuel" to "fuel-air," in item (*3*), line 5 change "mixtures" to "fuel-air ratios," in item (*4*), line 6 change "maximum knock mixture" to "maximum thermal-plug temperature," and in line 11 delete "for maximum knock mixture."

Section 8 (*b*).—Change to "Adjustment of Fuel-Air Ratio.—The fuel level shall then be adjusted to obtain maximum thermal-plug temperature as described in Section 7 (*b*)."

Section 8 (*c*).—In lines 3 and 4 change "sample" to "fuel"; in lines 6 and 7 change "its maximum knock mixture" to "the fuel-air ratio for maximum thermal-plug temperature."

Section 9 (*a*).—In line 1 change "sample" to "fuel."

Section 12.—In line 6 change "samples" to "fuels."

Section A4 (*c*).—Change this revision as preprinted to read as follows: "Valve Guides.—Cast iron. As installed, the difference in diameter between the valve stem and its guide shall be 0.0025 ± 0.0005 in. for the intake valve and 0.0035 ± 0.0005 in. for the exhaust valve."

Section A5 (*a*).—At the end of the present section, add the following paragraph: "As a safety precaution, a suitable water manometer may be connected to the air outlet pipe of the ice tower. A differential pressure appreciably in excess of 0.5 in. of water indicates undue restriction of the air flow, resulting from improper condition of the ice or plugging of the drain trap."

Test for Neutralization Number of Petroleum Products by Color-Indicator Titration (D 663 - 42 T), with the following sentence added at the end of the statement of scope:[7] "This method is not applicable to oils which form stable emulsions."

Test for Neutralization Number of Petroleum Products by Electrometric Titration (D 664 - 42 T)

Test for Rust-Preventing Characteristics of Turbine Oils (D 665 - 42 T)

Adopted as Standard:

Test for Oil Content of Paraffin Wax (D 721 - 43 T)

Test for Knock Characteristics of Motor Fuels (D 357 - 43 T), with the following additional revisions:[7]

Section 5 (*c*).—In line 1 change "0.025 in." to "0.015 to 0.025 in." Insert new Note 2 to read as follows: "NOTE 2.—In rating fuels of very high octane number, more satisfactory operation of spark plugs is obtained with a gap of less than 0.025 in., the latter being preferable in the motor-fuel range.

Section 5 (*o*).—Change title to "Fuel-Air Ratio for Maximum Knock."

Section 9 (*b*).—Delete and substitute the following: "The bouncing-pin adjustment shall not be considered satisfactory unless the knock-meter reading is zero when operating on a non-knocking reference fuel throughout the micrometer range over which the pin setting is to be used."

Section 11 (*a*).—Change "adjustment" to "readjustment."

Section 11 (*b*).—Change title to "Adjustment of Fuel-Air Ratio." In line 10 change "air-fuel" to "fuel-air," and in line 11 change "air-fuel" to "fuel-air."

Section 12 (*b*).—Change title to "Adjustment of Fuel-Air Ratio."

Section 12 (*d*).—In line 1 change "air-fuel" to "fuel-air."

Section A4 (*c*).—Change the first portion of this revision as preprinted to read as follows: "*Valve Guides*.—Cast iron. As installed, the difference in diameter between the valve stem and its guide shall be 0.0025 ± 0.0005 in. for the intake valve and 0.0035 ± 0.0005 in. for the exhaust valve."

Section A5 (*a*).—At the end of the present section, add the following paragraph: "As a safety precaution, a suitable water manometer may be connected to the air-outlet pipe of the ice tower. A differential pressure appreciably in excess of 0.5 in. of water indicates undue restriction of the air flow, resulting from improper condition of the ice or plugging of the drain trap."

Footnote 16.—Change to read as follows: "Note that the throttle plate originally used with the present type variable-float-level carburetor has been discarded."

Section A13 (*g*).—In line 5 change "oil" to ", or oil."

Test for Saponification Number of Petroleum Products (D 94 - 43 T), as revised

Conversion of Kinematic Viscosity to Saybolt Furol Viscosity (D 666 - 42 T)

Adopted as Standard, Revisions in:

Test for Gum Content of Gasoline (D 381 - 42)

Test for Sulfur in Petroleum Oils by Bomb Method (D 129 - 39)

Test for Viscosity by Means of the Saybolt Viscosimeter (D 88 - 38), with the following revision:[7]

Section 2 (c).—Add a footnote at the end of this section to read as follows: "Many years' experience with flasks conforming to these dimensions has proved them to be satisfactory for all but the most viscous oils. With the latter, drainage errors may occur if the length of the neck of the flask above the graduation mark varies excessively. As soon as stocks of flasks now on hand have been depleted, it is planned to revise the flask specification by limiting the length of the neck above the graduation mark to a maximum of 11 mm."

Withdrawal of Tentative Standard:

Spec. for Aviation Gasoline (D 615 - 41 T)

Accepted for Publication as Information Only:

Test for Potential Gum in Aviation Gasoline
Conversion Tables of Metric Tons in Vacuo to Long and Short Tons in Air, and *Vice Versa*
Oil Measurement (A statement of principles that have been accepted for methods of oil measurement)
Method for Analysis of Petroleum Sulfonates
Test for Saponification Number of Petroleum Products by Electrometric Titration

Sectional Committee Z11 on Petroleum Products and Lubricants:

Report, not preprinted, presented from manuscript by T. G. Delbridge, vice-chairman.

Committee D-8 on Bituminous Waterproofing and Roofing Materials:

Report presented by J. M. Weiss, chairman and the following actions taken:

Accepted as Tentative, Revisions in:

Spec. for Asphalt-Saturated Asbestos Felts for Use in Waterproofing and in Constructing Built-Up Roofs (D 250 - 42 T)
Spec. for Asphalt-Saturated and Asphalt-Coated Asbestos Felts for Use in Constructing Built-Up Roofs (D 655 - 42 T)
Testing Felted and Woven Fabrics Saturated with Bituminous Substances for Use in Waterproofing and Roofing (D 146 - 38 T)

Adopted as Standards:

Volume Correction Table for Tar and Coal-Tar Pitch (D 633 - 41 T), jointly with Committee D-4.
Spec. for Wide Selvage Asphalt Roofing Surfaced with Coarse Mineral Granules (D 371 - 41 T),[8] with a revision in Table I deleting from the tenth item in the table the words "per 108 sq. ft."
Spec. for Asphalt Siding Surfaced with Coarse Mineral Granules (D 699 - 42 T),[8] with a revision in Table I deleting from the ninth item in the table the words "per 100 sq. ft."

Adopted as Standard, Revisions in:

Spec. for Asphalt for Use in Constructing Built-Up Roof Coverings (D 312 - 41)
Spec. for Asphalt-Saturated Roofing Felt for Use in Waterproofing and in Constructing Built-Up Roofs (D 226 - 42)
Spec. for Coal-Tar Saturated Roofing Felt for Use in Waterproofing and in Constructing Built-Up Roofs (D 227 - 42), with a further revision in the new Section 2, changing "shall" to read "may."
Spec. for Woven Cotton Fabrics Saturated with Bituminous Substances for Use in Waterproofing (D 173 - 42)

Reaffirmation of Standards:

Spec. for Coal-Tar Pitch for Roofing, Dampproofing and Waterproofing D(450 - 41)
Test for Coarse Particles in Mixtures of Asphalt and Mineral Matter (D 313 - 41)

It was announced that the recommendation appearing in the report as preprinted for adoption as standard of the Tentative Methods of Sampling Bituminous Materials (D 140 - 41 T) had been withdrawn by the committee.

Committee D-4 on Road and Paving Materials:

Report presented by Prévost Hubbard, secretary, and the following actions taken:

Accepted as Tentative:

Test for Hot Extraction of Asphaltic Materials and Recovery of Bitumen by the Modified Abson Procedure

Adopted as Standard:

Spec. for Crushed Stone, Crushed Slag, and Gravel for Water-Bound Macadam Base and Surface Courses of Pavements D(694 - 42 T)
Spec. for Crushed Stone and Crushed Slag for Bituminous Macadam Base and Surface Courses of Pavements (D 693 - 42 T), with a revision[9] to replace the present Notes 1 and 2 in Section 5 by the following note:

---

[8] These recommendations, not preprinted, were accepted by unanimous consent, subject to favorable letter ballot of Committee D-8, which ballot has been favorable and the results are given in the report of the committee, see p. 420.

[9] This recommendation, not preprinted, was accepted by unanimous consent, subject to favorable letter ballot of Committee D-4, which ballot has been favorable and the results are given in the report of the committee, see p. 405.

Note.—Sizes have been selected from the Tentative Specifications for Standard Sizes of Coarse Aggregate for Highway Construction (A.S.T.M. Designation: D 448). An appropriate size should be selected for each use, depending on thickness of the base or surface course, quality of the aggregate, and on other local construction and service conditions.

For the harder aggregates, any of the sizes specified for penetration course aggregate may be appropriate, depending upon characteristics of the construction. For softer aggregates which tend to break down under the roller, the larger sizes should be used. The line of demarcation between harder and softer aggregates may be fixed conveniently by selection of limiting percentages of wear, Los Angeles machine, depending on characteristics of aggregates available in each locality.

The size of choke aggregate best suited for the work depends upon the size of surface voids in the penetration course and on fluidity of the bituminous binder. The more fluid binders require a densely graded choke aggregate (sizes 67 or 78), while the open gradations of aggregate are more suitable for the more viscous hot-application binders. The following combinations of size numbers are suggested:

Size of Penetration Course Aggregate	Size of Choke Aggregate	
	Viscous Binders	Fluid Binders
1.........	5	67
2.........	5 or 6	67 or 78
3.........	6 or 7	78

The size of seal coat aggregate depends upon the type of surface desired.

Volume Correction Table for Tar and Coal-Tar Pitch (D 633 – 41 T), jointly with Committee D-8.

Test for Moisture-Density Relations of Soil-Cement Mixtures (D 558 – 40 T) with revisions

Wetting-and-Drying Test of Compacted Soil-Cement Mixtures (D 559 – 40 T)

Freezing-and-Thawing Test of Compacted Soil-Cement Mixtures (D 560 – 40 T)

The above latter three recommendations were presented jointly with Committee D-18 on Soils for Engineering Purposes.[10]

Adopted as Standard, Revisions in:

Test for Ductility of Bituminous Materials (D 113 – 39)

Test for Abrasions of Coarse Aggregate by Use of the Los Angeles Machine (C 131 – 39)[11] jointly with Committee C-9 on Concrete and Concrete Aggregates, to incorporate the tentative revision[12] published since June, 1941, with the exception of the explanatory note.

SIXTH AND SEVENTH SESSIONS—SYMPOSIUM ON ANALYTICAL COLORIMETRY AND PHOTOMETRY

WEDNESDAY, JUNE 28, 9:30 A.M. AND 1:30 P.M.

SESSION CO-CHAIRMEN: PAST-PRESIDENT G. E. F. LUNDELL; J. J. STUMM

Past-President G. E. F. Lundell in opening the symposium sessions said that the series of papers on analytical colorimetry and photometry had been arranged in order to present a clear picture on the more recent developments for simpler and rapid methods of analysis.

The ever-increasing demands for speed and output of chemical determinations have forced the chemist to shorten methods of test to the absolute limit consistent with the accuracy that is needed. Important developments along this line have been the rapid improvement of apparatus for measuring the absorption of light by aqueous solutions, and of methods of test based on their use. He stated that during the symposium detailed consideration would be given to principles, apparatus, and applications and would include such topics as light, the derivation and use of laws, chemical principles, photoelectric cells, glass filters, filter photometers, spectrophotometers, errors involved in application of the instruments, the use of the methods in testing ferrous and non-ferrous metals, and bibliography.

The papers comprising the symposium were then presented at two sessions, as follows:

---

[10] These recommendations, not preprinted, were accepted by unanimous consent, subject to favorable letter ballots of Committees D-4 and D-18, which ballots have been favorable and the results are given in the reports of the committees, see p. 405 and p. 498.

[11] This recommendation, not preprinted, was accepted by unanimous consent, subject to favorable letter ballot of Committee D-4, which ballot has been favorable and the results are given in the report of the committee, see p. 405.

[12] 1943 Supplement to Book of A.S.T.M. Standards Part II, p. 162.

Sixth Session: Instruments Section

G. E. F. LUNDELL, CHAIRMAN

Colorimetric Analysis and Beer's Law—J. L. Hague, presented from manuscript by the author.

Photocells in Colorimetry—Ralph H. Muller, presented from manuscript by the author.

Glass Photometric Filters—O. A. Gage, presented from manuscript by the author.

Filter Photometers—A. E. Ruehle, presented from manuscript by the author.

Spectrophotometer Cells—S. E. Q. Ashley, presented from manuscript by the author.

Trends in Analytical Chemistry—B. L. Clarke, presented from manuscript by the author.

Spectrophotometers—K. S. Gibson, presented from manuscript by the author.

Physical Basis of Light—R. J. Kryter, illustrated talk.

Seventh Session: Chemical Section

J. J. STUMM, CHAIRMAN

Instrumental Errors—C. L. Luke, presented from manuscript by the author.

The Chemistry in Colorimetry—M. G. Mellon, presented from manuscript by the author.

Bibliography of Photoelectric Spectrophotometric Methods of Analysis for Inorganic Ions—J. W. Stillman, presented from manuscript by the author.

Methods for Aluminum Base Alloys—J. J. Stumm, presented by the author.

Methods for Magnesium Base Alloys—V. A. Stenger, presented by the author.

Methods for Other Non-Ferrous Alloys—C. Zischkau, presented by the author, who called upon the following individuals to describe applications of the methods to specific non-ferrous alloys:

F. M. Barry—Colorimetric Determination of Manganese in Copper Alloys.
R. P. Nevers—Phosphorus in Copper Base Alloys
O. P. Case—Silicon in Copper Base Alloys

Methods for Ferrous Alloys—Arba Thomas, presented from manuscript by the author, who called upon the following individuals to describe applications of the methods to specific ferrous alloys:

M. G. Mellon—Phosphorus in Alloy Steels
E. R. Vance—Molybdenum in Alloy Steels
W. J. Boyer—Colorimetric Methods for the Determination of Phosphorus, Manganese, Molybdenum and Titanium in Stainless steels

---

EIGHTH SESSION—PAINT, PAPER, SOAPS, TEXTILES

WEDNESDAY, JUNE 28, 1:30 P.M.

SESSION CO-CHAIRMEN: PAST-PRESIDENT H. J. BALL; E. W. McMULLEN

Committee D-13 on Textile Materials:

Report presented by W. H. Whitcomb, secretary, and the following actions taken:

Accepted as Tentative, Revisions in:

Testing and Tolerances for Glass Yarn (D 578 - 40 T)

Def. of Terms Relating to Textile Materials (D 123 - 43 T)

Testing and Tolerances for Tire Cord, Woven and on Cones (D 179 - 42)

Testing Wool Felt (D 461 - 40), with an editorial correction changing 20 *N* sodium hydroxide to read 0.05 *N* sodium hydroxide in the revised Section 18 (*c*) and (*d*),

Spec. for Textile Testing Machines (D 76 - 42)

Adopted as Standard:

Testing and Tolerances for Woven Tapes (D 259 - 42 T)

Testing and Tolerances for Certain Wool and Part Wool Fabrics (D 462 - 42 T)

Test for Commercial Weight of Rayon Staple (D 540 - 43 T)

Testing Asbestos Tubular Sleeving (D 628 - 41 T)

Testing and Tolerances for Certain Fine Staple Cotton Gray Goods (D 679 - 42 T)

Testing and Tolerances for Certain All-Cotton and Cotton-and-Rayon Fine Fancy Goods (D 680 - 42 T)

Def. of Terms Relating to Textile Materials (D 123 - 43 T)

Adopted as Standard, Revisions in:

Def. of Terms Relating to Textile Materials (D 123 - 42)
Testing and Tolerances for Cotton Yarns (D 180 - 42)
Testing and Tolerances for Continuous Filament Rayon Yarns (D 258 - 42)
Testing and Tolerances for Woolen Yarns (D 403 - 38)
Testing and Tolerances for Worsted Yarns (D 404 - 38)
Test for Fineness of Wool (D 419 - 37)
Testing and Tolerances for Woven Glass Fabrics (D 579 - 43)
Testing and Tolerances for Woven Glass Tapes (D 580 - 43)
Testing and Tolerances for Woven Glass Tubular Sleeving and Braids (D 581 - 43)
Spec. for Tolerances for Numbered Cotton Duck (D 230 - 27)
Spec. and Test for Asbestos Roving for Electrical Purposes (D 375 - 42)
Testing and Tolerances for Spun Rayon Yarns and Threads (D 507 - 42)
Testing Wool Felt (D 461 - 40)
Spec. and Test for Asbestos Tape for Electrical Purposes (D 315 - 41)

Reaffirmation of Standards:

Spec. and Test for Tire Fabrics Other than Cord Fabrics (D 122 - 37)
Spec. for 0.007 in. Cotton Tape for Electrical Purposes (D 335 - 36)
Spec. and Test for Holland Cloth (D 376 - 35)
Testing and Tolerances for Certain Light and Medium Weight Cotton Fabrics (D 274 - 36)
Determining Relative Humidity (D 337 - 34)
Test for Colorimetric Determination of Small Amounts of Copper and Manganese in Textiles (D 377 - 37)
Test for Strength of Rayon Woven Fabric When Wet (D 415 - 38)
Test for Colorfastness of Dyed or Printed Wool, Silk, or Rayon Fabric to Laundering or Domestic Washing (D 436 - 37)
Test for Shrinkage in Laundering of Woven Cotton Cloth (D 437 - 36)

Committee D-12 on Soaps and Other Detergents:

Report presented by H. P. Trevithick, chairman, and the following actions taken:

Accepted as Tentative:

Spec. for Liquid Toilet Soap, with an editorial correction changing "alkali" in Section 2 to read "alcohol"
Chemical Analysis of Industrial Metal Cleaning Compositions

Accepted as Tentative, Revisions in:

Spec. for Tetrasodium Pyrophosphate (Anhydrous) (D 595 - 42 T)
Def. of Terms Relating to Soaps and Other Detergents (D 459 - 43 T)
Sampling and Chemical Analysis of Special Detergents (D 501 - 43)

Adopted as Standard:

Spec. for Built Soap, Powdered (Type D) (D 533 - 42 T)
Spec. for Trisodium Phosphate (D 538 - 43 T)
Spec. for Compound Chip Soap (with Rosin) (D 690 - 42 T)
Spec. for Compound Powdered Soap (Granulated, with Rosin) (D 691 - 42 T)

Adopted as Standard, Revisions in:

Sampling and Chemical Analysis of Soaps and Soap Products (D 460 - 42)

Committee D-17 on Naval Stores:

Report presented by V. E. Grotlisch, chairman, and the following actions taken:

Accepted as Tentative:

Sampling and Testing Dipentene,[13] with editorial changes
Sampling and Testing Pine Oil,[13] with editorial changes
Testing Tall Oil,[13] with editorial changes
Definitions of Terms Relating to Tall Oil[13]

Accepted as Tentative, Revision in:

Sampling and Grading Rosin (D 509 - 38 T)

Accepted for Publication as Information Only:

Test for Unsaponifiable Matter in Rosin, with editorial changes

Committee D-6 on Paper and Paper Products:

Report presented by G. H. Harnden, secretary, and the following actions taken:

Accepted as Tentative:

Test for Adhesiveness of Gummed Tape, with a change in the table in Section 4 (*a*) in the requirement for smoothness "both sides" will be revised to read "each side"
Test for Bursting Strength of Paper

---

[13] These three methods and the definitions, which appeared in the preprinted report as information, were accepted by unanimous consent, subject to favorable letter ballot of Committee D-17, which ballot has been favorable and the results are given in the report of the committee, see p. 492.

Drop Test for Shipping Containers, with a revision in Section 1 (*b*) changing "100 lb." to read "120 lb."
Test for Effect of Heating on the Folding Endurance of Paper, changing "alternatively" to read "alternately" in Section 4 (*b*)
Test for Flammability of Treated Paper and Paperboard
Test for Hydrogen Ion Concentration (pH), changing "1 pH" to read "0.1 pH" in Section 8
Test for Time of Penetration by Water of Sized Paper and Paper Products (Dry Indicator Method), changing "beeswax" to read "wax" in two places in Fig. 3
Test for Printing Ink Permeation of Paper (Castor Oil Test)
Puncture and Stiffness Testing of Paperboard, Corrugated and Solid Fiberboard
Testing Containers in the Small Revolving Hexagonal Drum-Box Testing Machine
Test for Water Vapor Permeability of Paper and Paperboard

Adopted as Standard:

Test for Opacity of Paper and Paper Products (D 589 - 40 T), with an editorial change in Section 2 (*c*) omitting the words "illumination and " in the second sentence
Test for Moisture in Paper, Paperboard, and Paperboard and Fiberboard Containers (D 644 - 42 T)
Test for Basis Weight of Paper and Paper Products (D 646 - 42 T)
Conditioning Paper and Paper Products for Testing (D 685 - 42 T)
Quantitative Determination of Coating on Mineral-Coated Paper (D 687 - 42 T)
Test for Pentosans in Paper (D 688 - 42 T)
Test for Internal Tearing Resistance of Paper (D 689 - 42 T)

Committee D-16 on Industrial Aromatic Hydrocarbons:

Report presented by J. M. Weiss, chairman.

Committee D-1 on Paint, Varnish, Lacquer, and Related Products:

Report presented by H. E. Smith, chairman, and the following actions taken:

Accepted as Tentative:

Spec. for Raw Umber
Spec. for Burnt Umber
Spec. for Raw Sienna
Spec. for Burnt Sienna
Spec. for Venetian Red
Spec. for Yellow Iron Oxide Hydrated
Spec. for Black Synthetic Iron Oxide
Spec. for Isopropyl Alcohol
Test for Daylight 45 Degree, 0 Degree Apparent Reflectance of Paint Finishes
Test for Water in Lacquer, Solvents, and Diluents
Evaluating the Degree of Resistance to Flaking (Scaling) of Exterior Paints of the Linseed-Oil Type

Accepted as Tentative, Revisions in:

Def. of Terms Relating to Paint, Varnish, Lacquer, and Related Products (D 16 - 42 T)
Test for Specular Gloss of Paint Finishes (D 523 - 41 T)

Adopted as Standard:

Spec. for Basic Sulfate White Lead (D 82 - 42 T), as revised
Spec. for Isopropyl Acetate (D 657 - 42 T)
Sampling and Testing Aluminum Powder and Paste (D 480 - 42 T)
Test for Consistency of Exterior House Paints and Enamel-Type Paints (D 562 - 42 T)
Evaluating Degree of Resistance to Chalking of Exterior Paints of the Linseed-Oil Type (D 659 - 42 T)
Evaluating Degree of Resistance to Checking of Exterior Paints of the Linseed-Oil Type (D 660 - 42 T)
Evaluating Degree of Resistance to Cracking of Exterior Paints of the Linseed-Oil Type (D 661 - 42 T)
Evaluating Degree of Resistance to Erosion of Exterior Paints of the Linseed-Oil Type (D 662 - 42 T)
Test for Abrasion Resistance of Organic Coatings with Air Blast Abrasion Tester (D 658 - 42 T)
Test for Spectral Characteristics and Color of Objects and Materials (D 307 - 42 T), as revised

Adopted as Standard, Revisions in:

Spec. for Zinc Oxide (D 79 - 41)
Chemical Analysis of Dry Red Lead (D 49 - 37)
Sampling and Testing Lacquer Solvents and Diluents (D 268 - 42)
Spec. for Wood to be Used as Panels in Weather Tests of Paints and Varnishes (D 358 - 38), with the addition of the following as a footnote to the revised Section 1: "[a]These limitations do not apply to panels made of clapboard or siding of commercial types which shall be used as regularly marketed."

Papers:

Factors Influencing the Breaking Strength of Army and Navy Fabrics—Werner von Bergen, John C. Hintermaier, and Eric Ullman, presented from manuscript by Mr. von Bergen.

The Measurement of Fading Resistance of Camouflage Type Finishes by Accelerated Weathering—J. W. Iliff and L. B. Darrall, presented from manuscript by Mr. Iliff.

The Interpretation of Visual Rusting Standards—W. F. Singleton, presented from manuscript by the author.

NINTH SESSION—MARBURG LECTURE

WEDNESDAY, JUNE 28, 4:30 P.M.

SESSION CHAIRMAN: PRESIDENT DEAN HARVEY

In introducing the Nineteenth Edgar Marburg Lecturer, President Harvey stated that the lecture has been an institution of the Society for many years. Its purpose has been to have described at the annual meeting by leaders in their respective fields outstanding developments in the promotion of knowledge of engineering materials. The lecture had also been established to honor and perpetuate the memory of Edgar Marburg, the first Secretary-Treasurer of the Society.

He then presented Mr. Harold DeWitt Smith, The A. M. Tenney Associates, Inc., who had selected as the subject of his lecture "Textile Fibers—An Engineering Approach to an Understanding of Their Properties and Utilization." In his lecture Mr. Smith described the various textile fibers and the mechanical behavior of them as tiny microscopic beams. In his talk he developed a framework for a systematic engineering approach to a more complete understanding of textile fibers as structural materials, and discussed the new philosophy of textiles which has been created by the advent of manufactured fibers.

President Harvey, in expressing appreciation to Mr. Smith for an excellent presentation by one of its members on a subject of special interest to the A.S.T.M., presented to him on behalf of the Society, the Edgar Marburg Lecture Certificate.

TENTH SESSION—ADDRESSES: PRESIDENT HARVEY, AND DR. CHARLES K. LEITH

WEDNESDAY, JUNE 28, 8:15 P.M.

SESSION CHAIRMAN: PAST-PRESIDENT F. M. FARMER

Committee E-10 on Standards:

This report, presented by H. S. Vassar, chairman, recorded the large number of recommendations accepted during the year by Committee E-10 on behalf of the Society. It also discussed the activities of the committee in the promotion and expansion of A.S.T.M. standardization activities, and announced the organization during the year of three new committees on industrial aromatic hydrocarbons, metal powders and metal powder products, and adhesives.

Committee E-9 on Research:

In presenting this report, not preprinted, G. F. Jenks, chairman, stated that although, due to the war, very few new research programs had been undertaken during the year, a number of the committees had furthered their research. He referred particularly to a number of research projects on which further inspection data and information was being reported to the Society by the standing committees at this annual meeting.

Executive Committee:

This report, presented by Secretary Treasurer C. L. Warwick, discussed the war activities of the Society and its growth in membership as well as the number of additional activities undertaken during the past year. The report also summarized general Society work including membership, publications, finances, administrative matters, and cooperative relationships with other engineering societies.

Election of Officers:

The chairman then recognized T. G. Stitt, chairman of the Committee of Tellers, who reported results of the letter ballot on election of officers. Of the 1771 ballots cast, the results were as follows:

For President, to serve for one year:
P. H. Bates, 1770 votes.
For Vice-President, to serve for two years:
A. W. Carpenter, 1771 votes.
For members of the Executive Committee, to serve for two years:
W. C. Hanna, 1771 votes.
L. B. Jones, 1771 votes.
J. T. MacKenzie, 1771 votes.
Sam Tour, 1771 votes.

The chairman then introduced the newly elected members of the Executive Committee, requesting that they rise as their names were called.

At the request of the chairman, Past-Presidents H. S. Vassar and H. J. Ball escorted to the chair the Vice-President-Elect, A. W. Carpenter, who expressed appreciation for the honor conferred on him and the opportunity given by his election for further service to the Society. Mr. Carpenter stated that he was fully conscious of the responsibilities of the office, but that he was prepared to perform the duties assigned to him to the best of his ability.

The chairman then requested Past-Presidents A. C. Fieldner and W. M. Barr to escort to the chair the President-Elect, P. H. Bates, who spoke as follows in acknowledging the honor of his election:

Members and Guests of the A.S.T.M.: Just as there was nothing novel in the election of the officers, there will be nothing novel in my acceptance speech.

I find there have been so many officers elected to so many societies that there is no possibility of anyone in the future ever giving expression to his feelings in any new or novel way, and I can only do as has been often done before, say, I thank you and I hope to do the best I can and I appreciate the honor. But I assure you that I feel considerably more than that, although it cannot be expressed.

The Society, as has been pointed out, has had a remarkable growth and expansion in the last couple of years. The conditions of the past few years have been such that the efforts of the officers and the members and the Headquarters staff have developed such a large group of standards and have given them such a standing that commerce and industry, with its rapid expansion, found the need of a great variety of standards. As a consequence, they did count and do count upon the output of the Society, that is, its standards, and show their interest in the Society through membership, to this remarkable extent. I am certain that that is going to continue through the coming year, despite any inadequacies of the President you have elected. The effort which the members and all concerned have made for the life of this Society has been such that I am certain it is going to carry on, without any question, at the rate which it has attained. I thank you very much!

Recognition of Twenty-fifth Anniversary of Secretary-Treasurer and Assistant Treasurer:

Upon being recognized by the chairman, President Harvey, as a surprise feature, on behalf of the Society made appropriate recognition of a milestone reached by two of its officers, Secretary-Treasurer C. L. Warwick, and Assistant Treasurer J. K. Rittenhouse, upon completion of twenty-five years of service as officers of the Society. Testimonials and tokens of esteem were presented to each.

In responding Mr. Warwick expressed appreciation of this fine personal tribute. He said that he felt quite inexperienced when first elected to the office twenty-five years ago, but wished to acknowledge his good fortune in studying and working closely under Edgar Marburg, the first Secretary-Treasurer, and to several Past Presidents of the Society who had guided him and been an inspiration in his work. He also paid tribute to the members of the Headquarters staff and said that he wished to share the honor with them.

Presidential Address:

The chairman then presented the President, Dean Harvey, who delivered the annual presidential address entitled "The Art of Being a Materials Engineer."[14]

Address by Charles K. Leith:

The chairman then introduced Dr. Charles K. Leith, Mineral Consultant, War Production Board, who presented an address entitled "Minerals in War and Peace."[15]

Award of Honorary Memberships:

For the award of honorary memberships, the chairman called upon Past-President G. E. F. Lundell to present M. E. McDonnell; on Past-President H. H. Morgan to present R. P. Miller; and on Past-President T. G. Delbridge to present Dr. Hermann von Schrenk. Following each presentation, President Harvey made the award of honorary membership.

Recognition of Forty-Year Members:

The chairman announced that in accordance with action taken by the Executive Committee, certificates were being awarded this year to eight individuals and five companies who had attained 40 years of membership in the Society. Presentation of the certificates was then made by the Secretary-Treasurer to the following:

W. F. Angus, President, Dominion Bridge Co., Ltd.
Robert A. Cummings, Consulting Civil Engineer, Pittsburgh, Pa.
William R. Dunn, Denville, N. J.
C. S. Reeve, Technical Adviser, The Barrett Div., Allied Chemical and Dye Corp.
Alfred E. Roberts, Partner, Bull & Roberts, Consulting Chemists
Herbert L. Sherman, Treasurer, Skinner & Sherman, Inc.
Frank N. Speller, Metallurgical Consultant, Pittsburgh, Pa.
Sanford E. Thompson, President, The Thompson & Lichtner Co., Inc.
Dominion Bridge Company, Ltd., Montreal, Canada
Froehling & Robertson, Inc., Richmond, Va.
Illinois Central Railroad Co., Paducah, Ky.
Tufts College Engineering School, Tufts College, Mass.
Westinghouse Electric and Mfg. Co., East Pittsburgh, Pa.

ELEVENTH SESSION—STEEL, CORROSION OF IRON AND STEEL

THURSDAY, JUNE 29, 9:30 A.M.

SESSION CHAIRMAN: J. S. VANICK

Committee A-1 on Steel:

Report presented by N. L. Mochel, chairman, and the following actions taken:

Accepted as Tentative, Revisions in:

Spec. for Light Gage Structural Quality Flat Hot-Rolled Carbon Steel (0.2499 and 0.1874 in. to 0.0478 in. in Thickness) (A 245 - 42 T)
Spec. for Light Gage Structural Quality Flat Rolled Carbon Steel (0.0477 to 0.0225 in. in Thickness) (A 246 - 42 T)
Spec. for Alloy-Steel Bolting Materials for High-Temperature Service from 750 to 1100 F., Metal Temperatures (A 193 - 40 T) and
Spec. for Heat-Treated Carbon-Steel Bolting

---

[14] See p. 30.
[15] Published in the ASTM BULLETIN, No. 129, August, 1944, p. 18.

Material (A 261 – 43 T), with the following changes in the revisions as preprinted:[16]

Section 12 (b).—Reference to the A.I.S.I. Manual is to be deleted and the table of permissible variations inserted

Section 12 (c).—Delete the last sentence.

Spec. for Seamless Carbon-Molybdenum Alloy-Steel Pipe for Service at Temperatures from 750 to 1000 F (A 206 – 42 T)

Spec. for Lap-Welded and Seamless Steel Pipe for High-Temperature Service (A 106 – 42 T), with the following additional change:[16]

Section 14.—Add a new Paragraph (*c*) to read as follows: "(*c*) If definite lengths are not required, pipe may be ordered in single random lengths of 16 to 22 ft. with 5 per cent 12 to 16 ft., or in double random lengths with a minimum average of 35 ft. and a minimum length of 22 ft. with 5 per cent 16 to 22 ft."

Spec. for Seamless Alloy-Steel Pipe for Service at Temperatures from 750 to 1100 F. (A 158 – 42 T), with the following changes:[16]

Table I.—Change the manganese content of Grade P 8b from the present "3.0" to read "2.0" per cent; minimum percentage of titanium when added, to be "five times the carbon content with a maximum of 0.60 per cent"; and the minimum percentage of columbium, when added, to be "ten times carbon content with a maximum of 1.0 per cent."

Also, change the composition of grade P 8a as follows: Increase the carbon content from the present "0.07" to "0.08 per cent max."; chromium content range from "17.00 to 20.00" to "18.00 to 20.00 per cent."

Spec. for Carbon-Steel Castings Suitable for Fusion Welding for Service at Temperatures up to 850 F. (A 216 – 42 T), and,

Spec. for Alloy-Steel Castings Suitable for Fusion Welding for Service at Temperatures from 750 to 1100 F. (A 217 – 42 T), with the following changes:[16]

New Section.—Insert a new section to read as follows: "If specified in the inquiry, contract or order, and when mutually agreed upon by the manufacturer and the purchaser, castings to these specifications may be subject to magnetic particle testing and inspection. When so specified the magnetic particle inspection shall be in accordance with Tentative Test Method A. . . . , of the American Society for Testing Materials."

This action is to be taken concurrently with the approval of the proposed new tentative methods for magnetic particle inspection and testing of steel castings, now being submitted to letter ballot of Committee A-1

Spec. for Alloy-Steel Forgings for General Industrial Use (A 237 – 42)

Spec. for Carbon-Steel and Alloy-Steel Ring and Disk Forgings (A 243 – 43)

Adopted as Standard:

Spec. for Welded Alloyed Open-Hearth Iron Pipe (A 253 – 42 T),[16] as revised, in accordance with the preprinted report. (Note.—See note on Marking Clauses, below)

Spec. for Copper-Brazed Steel Tubing (A 254 – 42 T)[16]

Spec. for Welded and Seamless Steel Pipe Piles (A 252 – 42 T), with the following changes:[16]

Section 9 (a).—Change from its present form to read as follows:

> 9. (*a*) Unless otherwise agreed upon between the manufacturer and the purchaser, material shall be ordered in single or double lengths, and shall be furnished in accordance with the following regular practice:
> Single random lengths..... 16 to 25 ft., incl.
> Double random lengths.... over 25 ft. with a minimum average of 35 ft.

Section 10.—Change the last sentence of this section by the addition of the italicized words and figures: "Plain end material for welding, unless otherwise specified, shall be beveled to an angle of 30 deg., *with a tolerance of plus 5 deg., minus 0 deg.*, with a width of flat at the end of the pipe $\frac{1}{16} \pm \frac{1}{32}$ in."

Spec. for Manganese-Vanadium Steel Plates for Boilers and Other Pressure Vessels (A 225 – 39 T), with the following additional change:[16]

Section 14 (a).—Before the last sentence of this paragraph insert a new sentence to read as follows: "Plates, the maximum lengthwise and crosswise dimensions of which do not exceed 48 in., shall have the marking stamped in one place approximately midway between the center and an edge."

Adopted as Standard Revisions in:

Spec. for Carbon-Steel Castings for Miscellaneous Industrial Uses (A 27 – 42)

Spec. for Carbon-Steel and Alloy-Steel Castings for Railroads (A 87 – 42)

Spec. for Carbon-Steel Castings for Valves, Flanges, and Fittings for High-Temperature Service (A 95 – 41)

Spec. for Alloy-Steel Castings for Structural Purposes (A 148 – 42)

Spec. for Alloy-Steel Castings for Valves, Flanges, and Fittings for Service at Temperatures from 750 to 1100 F. (A 157 – 42)

Spec. for Carbon-Steel Castings Suitable for Fusion Welding for Miscellaneous Industrial Uses (A 215 – 41)

---

[16] These recommendations not preprinted, were accepted by unanimous consent, subject to favorable letter ballot of Committee A-1, which ballot has been favorable and the results are given in the report of the committee, see p. 66.

In the above six standard specifications add a new section as shown above in Tentative Specifications A 216 and A 217 referring to the proposed new methods of magnetic particle testing and inspection of castings, this action to be concurrent with the approval of the new methods.[16]

Spec. for Carbon-Steel Bars for Springs (A 14 – 42)

Spec. for Boiler and Firebox Steel for Locomotives (A 30 – 42)

Spec. for Multiple-Wear Wrought Steel Wheels (A 57 – 39)

Spec. for Carbon-Steel Bars for Springs, with Special Silicon Requirements (A 68 – 39)

Spec. for Carbon-Steel Plates for Stationary Boilers and Other Pressure Vessels (A 70 – 42)

Spec. for Carbon-Silicon Plates of Ordinary Tensile Ranges for Fusion-Welded Boilers and Other Pressure Vessels (A 201 – 43)

Spec. for Chrome-Manganese-Silicon (CMS) Alloy-Steel Plates for Boilers and Other Pressure Vessels (A 202 – 39)

Spec. for Low-Carbon Nickel-Steel Plates for Boilers and Other Pressure Vessels (A 203 – 42)

Spec. for Molybdenum-Steel Plates for Boilers and Other Pressure Vessels (A 204 – 42)

Spec. for High Tensile Strength Carbon-Silicon Steel Plates for Boilers and Other Pressure Vessels (Plates 4½ in. and Under in Thickness) (A 212 – 39)

Spec. for Heat-Treated Wrought Steel Wheels (A 244 – 42)

Spec. for Alloy-Steel Bolting Material for High-Temperature Service (A 96 – 39)

Section 14.—Make the same additional changes in this section as recommended above in Section 12 of Specifications A 193.

Spec. for Welded and Seamless Steel Pipe (A 53 – 42),[1] with the following additional change:[16]

Section 14 (a).—In the first sentence change "random lengths" to "single random lengths."

New Paragraph (c).—Add a new Paragraph (*c*) to read as follows: "(*c*) When standard weight or extra strong pipe is ordered in double random lengths, the minimum length shall be not less than 22 ft., with a minimum average for the order of 35 ft."

(Note.—See note on Marking Clauses, below)

Spec. for Black and Hot-Dipped Zinc-Coated (Galvanized) Welded and Seamless Steel Pipe for Ordinary Uses (A 120 – 42), with the following additional change:[16]

Section 12 (a).—Make the same change as recommended above in Section 14 (*a*) of Specifications A 53, and add a new Paragraph (*c*) to read the same as A 53.

(Note.—See note on Marking Clauses, below)

Spec. for Seamless Low-Carbon and Carbon-Molybdenum Steel Still Tubes for Refinery Service (A 161 – 40)

Spec. for Seamless Cold-Drawn Intermediate Alloy-Steel Heat-Exchanger and Condenser Tubes (A 199 – 40)

Spec. for Seamless Intermediate Alloy-Steel Still Tubes for Refinery Service (A 200 – 40)

Spec. for Seamless Carbon-Molybdenum Alloy-Steel Boiler and Superheater Tubes (A 209 – 42)

Spec. for Medium-Carbon Seamless Steel Boiler and Superheater Tubes (A 210 – 40)

(Note.—See note on Marking Clauses, below)

In each of the above five specifications, the revisions permit reduction from the basic minimum elongation in 2 in. of a specified percentage for each $\frac{1}{32}$ in. decrease in wall thickness below $\frac{5}{16}$ in. Also in each specification a formula for calculating the distance between the plates in the flattening test is being inserted. In the accompanying Table I values for the permissible elongation deduction are given and also values for the constant "*e*", part of the flattening test formula. The following example shows the new flattening test section for Standard Specifications A 161. The other specifications will have the same wording except for the values of "*e*" shown in the accompanying Table I.[16]

TABLE I.

Spec. No. and Grade	Deduction for Each $\frac{1}{32}$ in. Decrease in Thickness Below $\frac{5}{16}$ in. from the Basic Minimum, per cent	Values of Constant *e* for Flattening Test Formula
A 161		
Low Carbon	1.75	0.09
Carbon Molybdenum	1.50	0.08
A 199		
(All Grades)	1.50	0.08
A 200		
(All Grades)	1.50	0.08
A 209		
Carbon Molybdenum	....	....
All Grades	1.50	0.08
A 210		
Carbon	1.25	0.07
A 213		
Ferritic	1.50	0.08
Austenitic	1.75	0.09
A 135		
Grade A	1.75	....
Grade B	1.50	....

> A section of the tube, not less than 2½ in. in length, shall be flattened cold between parallel plates until the

opposite walls of the tube meet. No cracks or breaks in the metal shall occur until the distance between the plates is less than the calculated value of "H" by the following formula:

$$H = \frac{(1 + e)\,t}{e + t/D}$$

where:

H = distance between flattening plates in inches,
t = nominal wall thickness of tube in inches,
D = actual outside diameter of tube in inches, and
e = deformation per unit length (constant for a given grade of steel), 0.09 for low carbon grade and 0.08 for the carbon-molybdenum grade.

Evidence of laminations or burnt material shall not develop during the entire flattening process.

Spec. for Seamless Cold-Drawn Low-Carbon Steel Heat-Exchanger and Condenser Tubes (A 179 – 42)

Spec. for Seamless Steel Boiler Tubes for High-Pressure Service (A 192 – 40)

Make the same changes as recommended above in the five tubing specifications involving the flattening test formula, with values for "e" in each specification of "0.09."[16]

Spec. for Electric-Resistance-Welded Steel Pipe (A 135 – 42)

TABLE II.

Grade	T 8 or P 8	T 18	T 19	T 20	T 24
Carbon, max., per cent	0.08	0.08	0.08	0.08	0.08
Manganese, max., per cent	2.00	2.00	2.00	2.00	2.00
Phosphorus, max., per cent	0.03	0.03	0.03	0.03	0.03
Sulfur max., per cent	0.03	0.03	0.03	0.03	0.03
Silicon, max., per cent	0.75	0.75	0.75	0.75	0.75
Nickel, per cent	8.00 to 11.00	9.00 to 13.00	9.00 to 13.00	11.00 to 14.00	11.00 to 14.00
Chromium, per cent	18.00 to 20.00	17.00 to 20.00	17.00 to 20.00	16.00 to 18.00	18.00 to 20.00
Molybdenum, per cent	....	....	....	2.00 to 3.00	3.00 to 4.00
Titanium	....	[b]	....	....	....
Columbium	....	....	[c]	....	....

[b] Grade T 18 shall have a titanium content of not less than five times the carbon content and not more than 0.60 per cent.

[c] Grade T 19 shall have a columbium content of not less than ten times the carbon content and not more than 1.00 per cent.

Make the same change involving reduction in elongation as recommended above in the five tubing specifications, with percentage for grade A of 1.75 and for grade B of 1.50. In addition change the basic minimum elongation in 2 in. from the present values of 30 and 25 per cent, min., respectively, for grades A and B to read "35" and "30" per cent, respectively.[16]

Spec. for Seamless Alloy-Steel Boiler and Superheater Tubes (A 213 – 42)

(See Table I for changes in elongation and flattening test requirements.)

Spec. for Atomic-Hydrogen-Arc Welded and Electric-Resistance-Welded Alloy-Steel Boiler and Superheater Tubes (A 249 – 42)

Change Table I, Chemical Requirements, in each of the above two specifications in accordance with the accompanying Table II. In connection with this recommendation it should be noted that Emergency Alternate Provisions in the respective grades will be submitted to the Society through Committee E-10 on Standards.

Marking Clause in Pipe and Tubing Specifications.—The respective marking clauses in each of these pipe and tubing specifications listed below are to be changed,[16] first, so that the hydrostatic test pressure, if formerly required to be marked, shall be deleted from the required markings, and second, the required marking shall include the symbols "A.S.T.M." and the specification serial designation, for example, "A.S.T.M. A 53," or "A.S.T.M. A 206." This recommendation will provide for the deletion of the word "specification" if now required. The designations of the specifications affected are as follows: A 53 – 42, A 83 – 42, A 120 – 42, A 161 – 40, A 178 — 40, A 179 – 42, A 192 – 40, A 199 – 40, A 200 – 40, A 209 – 42, A 210 – 40, A 211 – 40, A 213 – 42, A 214 – 42, A 226 – 40, A 249 – 42, A 250 – 43, A 253 – 42 T.

Spec. for Factory-Made Wrought Carbon-Steel and Carbon-Molybdenum-Steel Welding Fittings (A 234 – 42), with the following changes:[16]

Section 3 (a).—Delete the words "forge welding" which appear in the first sentence.

Section 6 (d).—Delete the present Paragraph (*d*) and reletter the subsequent paragraphs accordingly.

Spec. for Forged or Rolled Alloy-Steel Pipe Flanges, Forged Fittings, and Valves and Parts for Service at Temperatures from 750 to 1100 F. (A 182 – 40), with the following changes:[16]

Table I.—Change grade F 8 from its present form to read as shown in the accompanying Table III, and add three new grades, as shown.

Section 10.—Change from its present form to read as follows:

10. Valve bodies or fittings and other pressure-containing parts shall be tested after machining to the hydrostatic pressure prescribed in the table below, and shall show no leaks. No hydrostatic test is required for welding neck or other flanges.

Primary Service Pressure Rating at 900 F., psi.	Standard Hydrostatic Test Pressure, psi.
300	900
400	1200
600	1800
900	2400
1500	4200
2500	7200

Withdrawal of Standards:

Spec. for Carbon-Steel and Alloy-Steel Blooms, Billets, and Slabs for Forgings (A 17 – 29)

Spec. for Forge-Welded Steel Pipe (A 136 – 34)

TABLE III.

Grade	F 8	F 8m	F 8c	F 8t
Carbon, max., per cent	0.08	0.08	0.08	0.08
Manganese, max., per cent	2.50	2.50	2.50	2.50
Phosphorus, max., per cent	0.035	0.035	0.035	0.035
Sulfur, max., per cent	0.030	0.030	0.030	0.030
Silicon, max., per cent	0.85	0.85	0.85	0.85
Chromium, min., per cent	18.00	17.00	17.00	17.00
Nickel, min., per cent	8.00	10.00	9.50	9.00
Molybdenum, min., per cent	.....	2.00	.....	.....
Titanium, per cent	.....	.....	.....	[e]
Columbium, per cent	.....	.....	[d]	.....

[d] Grade F 8c shall have a columbium content of not less than ten times the carbon content and not more than 1.00 per cent.

[e] Grade F 8t shall have a titanium content of not less than five times the carbon content and not more than 0.60 per cent.

Spec. for Riveted Steel and Wrought-Iron Pipe (A 138 – 34)

Reaffirmation of Standards:

Spec. for Steel for Bridges and Buildings (A 7 – 42)

Spec. for Structural Nickel Steel (A 8 – 39)

Spec. for Mild Steel Plates (A 10 – 39)

Spec. for Structural Silicon Steel (A 94 – 39)

Spec. for Structural Rivet Steel (A 141 – 39)

Spec. for One-Wear and Two-Wear Wrought Steel Wheels (A 186 – 39)

Spec. for Steel Tires (A 26 – 39)

It was announced that the committee had withdrawn the recommendation appearing in the preprinted report for the immediate adoption of revisions in the Standard Specifications for Steel Music Spring Wire (A 228 – 41).

Joint A.W.S.-A.S.T.M. Committee on Filler Metal:

Report presented, in the absence of the chairman, by title.

Committee A-10 on Iron-Chromium, Iron-Chromium-Nickel, and Related Alloys:

Report presented by Jerome Strauss, chairman, and the following actions taken:

Accepted as Tentative:

Spec. for Chromium-Nickel-Iron Alloy Castings (25-12 Class) for High-Temperature Service submitted jointly with Committee B-4.

Accepted as Tentative, Revisions in:

Spec. for Corrosion-Resisting Chromium Steel Clad Plate, Sheet, and Strip (A 263 – 43 T)

Spec. for Corrosion-Resisting Chromium-Nickel Steel Clad Plate, Sheet and Strip (A 264 – 43 T)

Adopted as Standard, Revisions in:

Spec. for Corrosion-Resisting Chromium and Chromium-Nickel Steel Plate, Sheet, and Strip for Fusion-Welded Unfired Pressure Vessels (A 240 – 43),[17] with a change in the description of No. 1 Finish in Section 17, revising it to read as follows:

> ***No. 1 Finish:***
> (*a*) Hot rolled, annealed, and pickled, or
> (*b*) Hot rolled, annealed, grit or sand blasted, and passivated.

Spec. for Corrosion-Resisting Chromium-Nickel Steel Plate, Sheet, and Strip (A 167 – 43),[17] with a change in the description of No. 1 Finish identical with that recommended above in Specifications A 240.

Spec. for Corrosion-Resisting Chromium Steel Plate, Sheet, and Strip (A 176 – 43),[17] with a change in the description of No. 1 Finish identical with that recommended above in Specifications A 240.

Spec. for High-Strength Corrosion-Resisting Chromium-Nickel Steel Sheet and Strip (A 177 – 43)

Committee A-5 on Corrosion of Iron and Steel:

Report presented by C. D. Hocker, chairman, and the following actions taken:

Accepted as Tentative:

Spec. for Lead Coating (Hot-Dip) on Iron or Steel Hardware

Tentative Standards Continued as Tentative Without Revision:

Spec. for Zinc-Coated (Galvanized) Iron or Steel Sheets (A 93 – 38 T)

---

[17] These recommendations, not preprinted, were accepted by unanimous consent, subject to favorable letter ballot of Committee A-10, which ballot has been favorable and the results are given in the report of the committee, see p. 128.

Spec. for Zinc-Coating (Hot-Dip) on Iron and Steel Hardware (A 153 – 42 T)
Spec. for Electrodeposited Coatings of Cadmium on Steel (A 165 – 40 T)
Spec. for Electrodeposited Coatings of Zinc on Steel (A 164 – 40 T)
Test for Local Thickness of Electrodeposited Coatings (A 219 – 40 T)

Joint Research Committee on Effect of Temperature on the Properties of Metals:

Report presented by N. L. Mochel, chairman. The following two papers appended to the report were then presented:

Study of Effects of Variables on the Creep Resistance of Steels—H. C. Cross and W. Simmons, presented by N. L. Mochel.
Correlation of Short- and Long-Time Elevated Temperature Test Methods, presented by John Worth.

Committee A-3 on Cast Iron:

Report presented by J. W. Bolton, chairman

Committee E-4 on Metallography:

Report presented by L. L. Wyman, chairman, and the following actions taken:

Accepted as Tentative, Revisions in:

Preparation of Metallographic Specimens (E 3 – 42 T)
Preparation of Micrographs of Metals and Alloys (Including Recommended Practice for Photography as Applied to Metallography (E 2 – 39 T)

Committee A-2 on Wrought Iron:

Report, not preprinted, in the absence of the chairman, was presented by title.

Committee A-6 on Magnetic Properties:

Report presented by Thomas Spooner, chairman, and the following actions taken:

Accepted as Tentative:

Def. of Terms, With Symbols, Relating to Magnetic Testing, to replace Standard Definitions A 127

Adopted as Standard:

Test for Permeability and Core Loss of Flat-Rolled Magnetic Materials Using 28-cm Specimen (A 257 – 43 T)
Test for Normal and Incremental Permeability and Core Loss of Flat-Rolled Magnetic Materials at Low Alternating Inductions Using 28-cm. Specimen (A 258 – 43 T)
Test for Permeability of Feebly Magnetic Materials (A 259 – 43 T)

Adopted as Standard, Revisions in:

Test for Magnetic Properties of Iron and Steel (A 34 – 42)

Committee A-7 on Malleable-Iron Castings:

Report presented by H. A. Schwartz, secretary, and the following actions taken:

Accepted as Tentative, Revisions in:

Spec. for Pearlitic Malleable Iron Castings (A 220 – 39 T)
Spec. for Malleable Iron Castings (A 47 – 33)
Spec. for Cupola Malleable Iron (A 197 – 39)

Paper:

The Technical Cohesive Strength of Some Steels and Light Alloys at Low Temperatures —D. J. McAdam, Jr., R. W. Mebs, and G. W. Geil, presented by Mr. McAdam.

TWELFTH SESSION—CEMENTITIOUS AND MASONRY MATERIALS

THURSDAY, JUNE 29, 9:30 A.M.

SESSION CO-CHAIRMEN: VICE-PRESIDENT P. H. BATES; J. C. PEARSON

Committee C-7 on Lime:

Report presented by W. C. Voss, chairman, and the following actions taken:

Accepted as Tentative:

Definitions of Terms Relating to Quicklime[18]

Adopted as Standard:

Def. of Terms Relating to Lime (C 51 – 41 T)[18]

Adopted as Standard Revisions in:

Spec. for Hydrated Lime for Structural Purposes (C 6 – 31),[18] with changes eliminating references to Masons' hydrate and confining these specifications to normal hydrated lime for finishing.
Chemical Analysis of Limestone, Quicklime, and Hydrated Lime (C 25 – 29)[18]

A Report of the Subcommittee on Use of the Autoclave for Testing Limes, which will contain a digest of data reported by seven laboratories on studies of the expansion characteristics of lime for masonry purposes, was accepted for publication, subject to review by Committee E-6 on Papers and Publications.

---

[18] These recommendations, not preprinted, were accepted by unanimous consent, subject to favorable letter ballot of Committee C-7 which ballot has been favorable and the results are given in the report of the committee, see p. 318.

Committee C-12 on Mortars for Unit Masonry:

Report presented by T. I. Coe, vice-chairman, and the following actions taken:

Accepted as Tentative, Revisions in:

Spec. for Mortar for Reinforced Brick Masonry (C 161 – 41 T)

Adopted as Standard:

Spec. for Aggregate for Masonry Mortar (C 144 – 42 T)

Committee C-1 on Cement:

Report presented by P. H. Bates, chairman, and the following actions taken:

Accepted as Tentative:

Test for Determining the Air Content of Portland-Cement Mortar, with the addition of an explanatory footnote showing the derivation of the formula for calculating air content
Test for Determining Vinsol Resin in Portland Cement by the Methoxyl Method
Test for Heat of Hydration of Portland Cement

Accepted as Tentative, Revisions in:

Spec. for Treated Portland Cement for Concrete Pavements (C 175 – 42 T), with the addition in Table I of "AEA" (air entraining agent) after Darex, and the addition of "respective" before "chemical" and "physical," respectively, in Sections 4 and 5

Adopted as Standard:

Chemical Analysis of Portland Cement (C 114 – 42 T), Sections 1 to 8 only
Test for Compressive Strength of Portland-Cement Mortars (C 109 – 43 T), as revised

Adopted as Standard, Revisions in:

Spec. for Portland Cement (C 150 – 42), with the addition of "respective" before "chemical" and "physical," respectively, in Sections 4 and 5
Sampling and Physical Testing of Portland Cement (C 77 – 40), comprising the following seven separate methods:
  Sampling Hydraulic Cement
  Test for Fineness of Hydraulic Cement by the No. 200 Sieve
  Test for Normal Consistency of Hydraulic Cement
  Test for Soundness of Hydraulic Cement Over Boiling Water (Pat Test)
  Test for Time of Setting of Hydraulic Cement by the Vicat or Gillmore Needles
  Test for Tensile Strength of Hydraulic-Cement Mortars
  Test for Specific Gravity of Hydraulic Cements
Chemical Analysis of Portland Cement (C 114 – 42)

Accepted for Publication as Information Only:

Proposed Method of Chemical Analysis for Darex in Portland Cement

Committee C-15 on Manufactured Masonry Units:

Report presented by D. E. Parsons, chairman, and the following actions taken:

Accepted as Tentative, Revisions in:

Spec. for Glazed Building Units (C 126 – 39 T)

Adopted as Standard:

Spec. for Building Brick (Made from Clay or Shale) (C 62 – 41 T)

Adopted as Standard, Revisions in:

Spec. for Hollow Load-Bearing Concrete Masonry Units (C 90 – 39)
Methods of Sampling and Testing Brick (C 67 – 41), adoption of Tentative Method of Test for Initial Rate of Absorption (Suction) and Efflorescence of Brick (C 67 – 42 T), as revised.

Reaffirmation of Standards:

Spec. for Concrete Building Brick (C 55 – 37)
Spec. for Sand-Lime Building Brick (C 73 – 39)
Spec. for Structural Clay Floor Tile (C 57 – 39)
Spec. for Hollow Non-Load-Bearing Concrete Masonry Units (C 129 – 39)
Spec. for Concrete Masonry Units for Construction of Catch Basins and Manholes (C 139 – 39)
Sampling and Testing Structural Clay Tile (C 112 – 36)
Def. of Terms Relating to Structural Clay Tile (C 43 – 36)
Sampling and Testing Concrete Masonry Units (C 140 – 39)

Committee C-16 on Thermal Insulating Materials:

Report presented by E. T. Cope, chairman, and the following actions taken:

Accepted as Tentative:

Spec. for 85 per cent Magnesia Thermal Insulating Cement, formerly Emergency Specifications ES – 8, with the following changes:

Section 1.—Change the lower operating temperature from "212 F." to "200 F."

Section 2.—Change the introduction to the composition requirements to read as follows by the addition of the italicized words and figures:

> 2. The cement shall conform to the following requirements as to composition (*on the moisture-free basis, employing the methods of analysis given in Federal Specification HH-M-61, Sections F-3a to F-3g, inclusive*).

Section 3.—Change the requirement for dry covering capacity from "55" to "50" bd. ft. per 100 lb. of dry cement, min.; also change the requirement for volume change (shrinkage) upon drying from "30" to "35" per cent, max.

Section 4 (e).—Change the first sentence in the second paragraph to read as follows: Test specimens shall be molded in a mold of suitable size and shape for the guarded hot plate to be used, and 1½ in. in depth. Also change the requirement for size of steel plate from "12 in." to "14 or 15 in."

Spec. for Long-Fiber Asbestos Thermal Insulating Cement, formerly Emergency Specifications ES - 9, with the following changes:

Section 1.—Change the words "composed predominantly of" to "comprising"; also change the lower operating temperature limit from "200 F." to "140 F."

Section 2.—Omit the word "predominantly" and change grade "6" to "7."

Section 3.—Omit the requirement for "adhesion to steel."

Section 4.—In Paragraph (*e*) make the same changes as given above in Section 4 (*e*) of the Specifications for 85 per cent Magnesia Thermal Insulating Cement. Omit Paragraph (*f*) which describes the test for adhesion to steel.

Spec. for Mineral Wood Thermal Insulating Cement, formerly Emergency Specifications ES - 10, with the following changes:

Section 1.—Change the operating temperatures from "200 and 1200 F." to "140 and 1800 F."

Section 2.—Change the requirement for dry covering capacity from "40" to "45" bd. ft. per 100 lb. of dry cement, min.; change the requirement for volume change (shrinkage) upon drying from "25" to "20" per cent, max.; also change the thermal conductivity requirements at mean temperature of 200 F. from "0.90" to "0.80," at mean temperature of 500 F. from "1.00" to "0.90," at mean temperature of 700 F. from "1.10" to "1.00"-also change the requirement for adhesion to steel to "3.0 psi., min."

Section 3.—In Paragraph (*e*) make the same changes as given above in Section 4 (*e*) of the Specifications for 85 per cent Magnesia Thermal Insulating Cement; also revise the test for adhesion to steel in Paragraph (*f*) to use the apparatus described in the Navy Specification 32C14d.

Spec. for Expanded or Exfoliated Mica Thermal Insulating Cement, formerly Emergency Specifications ES - 11, with the following changes:

Title and Section 1.—Change the word "mica" to "vermiculite;" also change the lower operating temperature limit from "200 F." to "140 F."

Section 2.—Change the requirement for volume change (shrinkage) upon drying from "30" to "18" per cent, max.; also change the requirements for thermal conductivity at mean temperature of 200 F. from "1.10" to "0.95," at mean temperature of 500 F. from "1.20" to "1.10," at mean temperature of 700 F. from "1.30" to "1.20"; also change the requirement for adhesion to steel to "2.5 psi., min."

Section 3 (e).—Make the same changes as given above in Section 4 (*e*) of the Specifications for 85 per cent Magnesia Thermal Insulating Cement.

Spec. for Diatomaceous Silica Thermal Insulating Cement, for Use from 1200 to 1900 F., formerly Emergency Specifications ES - 13, with the following changes:

Section 1.—Omit the word "calcined" and also change the lower operating temperature limit from "1200 F." to "600 F." Also omit the note following this section.

Section 3 (e).—Make the same changes as given above in Section 4 (*e*) of the Specifications for 85 per cent Magnesia Thermal Insulating Cement.

Adopted as Standard:

Sampling and Mixing Thermal Insulating Cement (C 163 - 41 T)

Test for Bulk Density of Thermal Insulating Cement (C 164 - 41 T)

Test for Thickness and Density of Blanket Type Thermal Insulating Materials (C 167 - 41 T)

Def. of Terms Relating to Thermal Insulating Materials (C 168 - 41 T)

Committee C-8 on Refractories:

Report presented by J. D. Sullivan, chairman, and the following actions taken:

Accepted as Tentative:

Symbols for Heat Transmission to replace Standard C 108 - 41

Accepted as Tentative, Revisions in:

Spec. for Air-Setting Refractory Mortars (Wet Type) for Boiler and Incinerator Services (C 178 - 43 T)
Test for Pyrometric Cone Equivalent (P.C.E.) of Refractory Materials (C 24 - 42)
Spec. for Ground Fire Clay as a Mortar for Laying-Up Fireclay Brick (C 105 - 41)

Adopted as Standard:

Spec. for Fireclay Plastic Refractories for Boiler and Incinerator Services (C 176 - 42 T)[19]

Papers:

The following papers were presented:

The Effects of Certain Variations in Consistency and Curing Conditions on the Compressive Strengths of Cement-Lime Mortars—G. J. Fink, presented by the author.
The Reaction of Vinsol Resin as It Affects the Air Entrainment of Portland Cement Concrete[20]—Charles E. Wuerpel and Albert Weiner, presented by Mr. Wuerpel.
Comparative Tests of 52 Brands of Portland Cement From 15 Countries—E. V. Barrett, presented by John S. Peck.

THIRTEENTH SESSION—NON-FERROUS METALS AND ALLOYS, CORROSION POWDER METALS

THURSDAY, JUNE 29, 2 P.M.

SESSION CHAIRMAN: J. H. FOOTE

Committee B-5 on Copper and Copper Alloys, Cast and Wrought:

Report presented by J. J. Kanter, vice-chairman, and the following actions taken:

Accepted as Tentative, Revisions in:

Spec. for Cartridge Brass Sheet, Strip, and Disks (B 19 - 42 T)
Spec. for Bronze Castings for Turntables and Movable Bridges and for Bearing and Expansion Plates of Fixed Bridges (B 22 - 42 T)
Spec. for Copper-Base Alloys in Ingot Form for Sand Castings (B 30 - 42 T)
Spec. for Brass Sheet and Strip (B 36 - 43 T)
Spec. for Leaded Brass Sheet and Strip (B 121 - 43 T)
Spec. for Copper-Base Alloy Forging Rods, Bars, and Shapes (B 124 - 42 T)
Spec. for Cartridge Brass Cartridge Case Cups (B 129 - 43 T)
Spec. for Gilding Metal Sheet and Strip (B 130 - 43 T)
Spec. for Gilding Metal Bullet Jacket Cups (B 131 - 43 T)
Spec. for Leaded High-Strength Yellow Brass (Manganese Bronze) Sand Castings (B 132 - 41 T)
Spec. for Copper Rods, Bars, and Shapes (B 133 - 42 T)
Spec. for Brass Wire (B 134 - 42 T)
Spec. for Phosphor Bronze Rods, Bars, and Shapes (B 139 - 42 T)
Spec. for Tin-Bronze and Leaded Tin-Bronze Sand Castings (B 143 - 42 T)
Spec. for High-Leaded Tin-Bronze Sand Castings (B 144 - 42 T)
Spec. for Leaded Red Brass and Leaded Semi Red Brass Sand Castings (B 145 - 42 T)
Spec. for Leaded Yellow Brass Sand Castings for General Purposes (B 146 - 42 T)
Spec. for High-Strength Yellow Brass and High-Strength Leaded Yellow Brass Sand Castings (B 147 - 42 T)
Spec. for Aluminum Bronze Sand Castings (B 148 - 42 T)
Spec. for Leaded Nickel-Brass and Nickel-Bronze Sand Castings (B 149 - 42 T)
Spec. for Aluminum Bronze Rods, Bars and Shapes (B 150 - 41 T)
Spec. for Copper-Nickel-Zinc Alloy Rod and Wire (B 151 - 42 T)
Spec. for Copper Sheet, Strip, and Plate (B 152 - 41 T)
Spec. for Phosphor Bronze Wire (B 159 - 43 T)
Spec. for Aluminum Bronze Sheet and Strip (B 169 - 42 T)

Adopted as Standard, Revisions in:

Spec. for Free-Cutting Brass Rod for Use in Screw Machines (B 16 - 42)
Spec. for Steam or Valve Bronze Castings (B 61 - 42)
Spec. for Composition Brass or Ounce Metal Castings (B 62 - 41)

---

[19] This recommendation, not preprinted, was accepted by unanimous consent, subject to favorable letter ballot of Committee C-8, which ballot has been favorable and the results are given in the report of the committee, see p. 332.

[20] Published in ASTM BULLETIN, No. 130, October 1944, p. 41.

Spec. for Bronze Castings in the Rough for Locomotive Wearing Parts (B 66 – 38)

Spec. for Car and Tender Journal Bearings, Lined (B 67 – 38)

Spec. for Copper-Silicon Alloy Sheet for General Purposes (B 97 – 41)

Spec. for Copper-Silicon Alloy Rods, Bars, and Shapes (B 98 – 42)

Spec. for Rolled Copper-Alloy Bearing and Expansion Plates for Bridges and Other Structural Uses (B 100 – 43)

Spec. for Phosphor Bronze Sheet and Strip (B 103 – 43)

Withdrawal of Standard:

Spec. for Castings of the Alloy: Copper 88 per cent, Tin 8 per cent, Zinc 4 per cent (B 60 – 41),[21] including the proposed revisions in the report as preprinted

Committee B-1 on Copper and Copper-Alloy Wires for Electrical Conductors:

Report, not preprinted, presented from manuscript by J. H. Foote, chairman, and the following actions taken:

Accepted as Tentative:

Spec. for Lead-Coated and Lead-Alloy-Coated Soft Copper Wire for Electrical Purposes,[22] formerly Emergency Specifications ES – 1a, with the following changes: (*1*) elimination of reference to hard-drawn wires, deleting provisions relating thereto; (*2*) addition of the word "soft" in the title and scope; and (*3*) changes in the numerical values of requirements for resistivity to those prescribed in the Standard Specifications for Tinned Soft or Annealed Copper Wire for Electrical Purposes (A.S.T.M. Designation: B 33).

Adopted as Standard, Revisions in:

Spec. for Concentric-Lay-Stranded Copper Conductors, Hard, Medium-Hard, or Soft (B 8 – 41),[22] the changes comprising the incorporation in the standard of the Emergency Alternate Provisions EA – B 8 which provide for the inclusion optionally of lead or lead-alloy coated wires as well as tin and bare wires and, in addition, including a revision in Section 2 (*a*) changing it to read as follows by the addition of the italicized words: "The purchaser shall designate the type of wire *and the kind of coating, if any,* to be used in the conductor."

Committee B-4 on Electrical-Heating, Electrical-Resistance, and Electric-Furnace Alloys:

Report presented by Dean Harvey, chairman, and the following actions taken:

Accepted as Tentative:

Spec. for Chromium-Nickel-Iron Alloy Castings for High Temperature Service, submitted jointly with Committee A-10 on Iron-Chromium, Iron-Chromium-Nickel and Related Alloys, with the following revisions:[23]

Title.—Omit the words "for Electric Furnaces" and add "(25-12 Class)" after the word "Castings."

Section 1.—In the first sentence change "24" to read "25" per cent chromium, and add the words "petroleum still tube supports" after "electric furnaces."

Section 7.—Change to read as follows:

7. The purchaser shall specify not more than two tests. The tests shall be selected from the following list, with the restriction that not more than one of the tension tests at high temperature (that is, items (*3*) or (*4*)) may be required:

(*1*) Tension test after aging.
(*2*) Magnetic permeability test.
(*3*) Stress-rupture test.
(*4*) Short-time high-temperature tension test.

Appendix.—Omit the information on creep test in the Appendix.

Test for Equivalent Yield Stress of Thermostat Metals

Accepted as Tentative, Revisions in:

Spec. for Drawn or Rolled Alloy, 80 per cent Nickel, 20 per cent Chromium, for Electrical Heating Elements (B 82 – 41)

Spec. for Drawn or Rolled Alloy, 60 per cent Nickel, 15 per cent Chromium, and Balance Iron, for Electrical Heating Elements (B 83 – 41)

Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys:

Report presented by Sam Tour, chairman, and the following actions taken:

Accepted as Tentative:

Method of Alternate Immersion Testing of Non-Ferrous Metals[24]

---

[21] This recommendation, not preprinted, was accepted by unanimous consent, subject to favorable letter ballot of Committee B-5 which ballot has been favorable and the results are given in the report of the committee, see p. 244.

[22] These recommendations, not preprinted, were accepted by unanimous consent, subject to favorable letter ballot of Committee B-1, which ballot has been favorable and the results are given in the report of the committee, see p. 219.

[23] This recommendation, not preprinted, was accepted by unanimous consent, subject to favorable letter ballot of Committee B-4, which ballot has been favorable and the rsults are given in the report of the committee, see p. 241.

[24] These recommendations, not preprinted, were accepted by unanimous consent, subject to favorable letter ballot of Committee B-3, which ballot has been favorable and the results are given in the report of the committee, see p. 222.

Accepted as Tentative, Revisions in:

Method of Salt Spray Testing of Non-Ferrous Metals (B 117 - 41 T)[24]

Committee B-9 on Metal Powders and Metal Powder Products:

Report presented by W. A. Reich, chairman.

Papers:

The following papers were presented:

Evolution of Test Specimens for Non-Ferrous Castings—A. J. Smith, presented by J.W. Bolton.

An Alternate Immersion Test for Aluminum-Copper Alloys—R. B. Mears, C. J. Walton, and G. G. Eldredge, presented by Mr. Walton.

Basic Requirements in the Standardization of the Salt Spray Corrosion Test—Leo J. Waldron, presented from manuscript by the author.

FOURTEENTH SESSION—CONCRETE

THURSDAY, JUNE 29, 2 P.M.

SESSION CHAIRMAN: H. F. CLEMMER

Committee C-9 on Concrete and Concrete Aggregates:

Report presented by F. E. Richart, vice-chairman, and the following actions taken:

Accepted as Tentative:

Method for Making and Curing Concrete Compression and Flexure Specimens in the Laboratory

Test for Surface Moisture in Fine Aggregate (C 70 - 44 T), as a revision of and replacing Standard C 70 - 30, with the addition to Section 5 of the following explanatory footnote showing the derivation of the formula for calculating surface moisture:

NOTE.—These formulas are readily derived from basic relationships. For convenience express P_1 in terms of the ratio r, that is, the ratio of the weight of surface moisture to the weight of the saturated, surface-dry sample. It follows that:

$$r = \frac{W_s - \dfrac{W_s}{1+r}}{\dfrac{W_s}{1+r}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

If G is bulk specific gravity of the saturated-surface-dry fine aggregate, then

$$V_s = \frac{W_s}{G(1+r)} + \left(W_s - \frac{W_s}{1+r}\right) \quad \ldots\ldots (2)$$

where the first term gives the water displaced by the saturated-surface-dry fine aggregate and the second that displaced by the surface moisture.

From Eq. 2:

$$\frac{W_s}{1+r} = \frac{V_s - W_s}{\dfrac{1}{G} - 1} \quad \ldots\ldots\ldots\ldots\ldots (3)$$

By definition,

$$W_s = V_d G \quad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Substituting for $\frac{W_s}{1+r}$ and W_s in Eq. 1 and simplifying,

$$r = \frac{V_s - V_d}{W_s - V_s} \quad \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

The formula for P_2 may be derived by similar reasoning, or directly from that for P_1 since,

$$P_2 = \frac{\dfrac{V_s - V_d}{W_s - V_s}}{1 + \dfrac{V_s - V_d}{W_s - V_s}} \times 100 \quad \ldots\ldots\ldots (6)$$

Accepted as Tentative, Revisions in:

Test for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate (C 88-41 T), except for the proposed revision in Section 4 (*b*) as preprinted, which was withdrawn by the committee.

Test for Efficiency of Materials for Curing Concrete (C 156 - 40 T), with the following additional changes:[25]

Title and Sections 1 and 7.—Change "Materials" to "Methods."

Section 8 (*a*).—Change the last sentence to read as follows: "In order to provide for uniform air distribution, dummy molds shall be used to fill the shelf of the cabinet when it is not filled with test specimens.

Section 8 (*b*).—Add the following sentence following the third sentence in this section: "Sufficient space shall be provided in the cabinet above the test specimens so that the moving air will not be deflected in such manner as to pass over the specimens in a horizontal plane."

Section 9 (*c*).—Change to read as follows:

(*c*) The curing material shall then be uniformly applied to the surface of the specimen at the rate of coverage specified for that method of curing. It is advisable to apply curing agents to only one specimen at a time in an atmosphere of controlled temperature and humidity as prescribed in Section 5 (*b*). Liquids shall be sprayed on. The proper coverage shall be

---

[25] These recommendations, not preprinted, were accepted by unanimous consent, subject to favorable letter ballot of Committee C-9, which ballot has been favorable and the results are given in the report of the committee, see p. 341.

> determined by weighing the spray gun before and after application to 0.1 g.
>
> (*d*) Paper, blankets or burlap shall receive an additional sealing where they come in contact with the mold in order to prevent moisture loss except through the curing medium. In cases where a blanket having a thickness greater than ⅛ in. is used, the exposed edges, where they project above the mold, shall also be sealed. Liquid curing materials or granular curing materials shall be applied uniformly.

Insert the following new Paragraphs (*e*) and (*f*), relettering the present Paragraph (*d*) as (*g*):

> (*e*) Blankets or burlap intended for field use in a continuously wet condition shall be kept wet during the entire period of test. Similar materials intended for field use with but one initial wetting shall be applied in a wet condition but shall not be subsequently wetted during the period of test.
>
> (*f*) Where the method under investigation involves the use of a combination of curing agents, such as the use of a membrane or paper following a preliminary wet curing, the time of application of the final curing agent shall be in accordance with the governing specifications.

Adopted as Standard:

Methods of Sampling Fresh Concrete (C 172 - 42 T)

Methods of Measuring Length of Drilled Concrete Cores (C 174 - 42 T)

Def. of Terms Relating to Concrete and Concrete Aggregates (C 125 - 42 T)

Spec. for Ready-Mixed Concrete (C 94 - 43 T), as revised

Adopted as Standard, Revisions in:

Spec. for Concrete Aggregates (C 33 - 42)

Test for Structural Strength of Fine Aggregate Using Constant Water-Cement-Ratio Mortar (C 87 - 42)

Test for Compressive Strength of Concrete Using Portions of Beams Broken in Flexure (Modified Cube Method) (C 116 - 42), with the following additional changes:[25]

Section 1.—Add the following note: "Note.—For method of making flexural strength test, see the Standard Method of Test for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading) (A.S.T.M. Designation: C 78)."

Section 3.—Delete the present note and add the following new note: "Note.—Neat portland or alumina cement and suitable mixtures of sulfur with granular materials are recognized as suitable for capping hardened concrete specimens. Sulfur cap should be allowed to harden for at least 1 hr. before applying load; cement caps for a sufficient period to comply with the requirements prescribed in Paragraph (*b*)."

Test for Coal and Lignite in Sand (C 123 - 39), with an additional change revising the seventh sentence in Section 3 to read as follows: "The decanting particles contained on the gauze or sieve shall be washed in carbon tetrachloride, until the flotation liquid is removed, and then dried. The particles will dry very quickly, but may be placed in an oven at 105 C. for a few minutes if desired."

Test for Abrasion of Coarse Aggregate by Use of the Los Angeles Machine (C 131 - 39), jointly with Committee D-4 on Road and Paving Materials.

Method of Making and Storing Compression Test Specimens of Concrete in the Field (C 31 - 42), with the addition of the phrase "or as the basis for acceptance" to appear after "concrete" in the first sentence in Sections 7 (*b*) and 11 (*a*).

Test for Compressive Strength of Concrete (C 39 - 42)

Methods of Securing and Testing Specimens of Hardened Concrete from the Structure (C 42 - 42)

Test for Flexural Strength of Concrete (Laboratory Method Using Simple Beam with Third-Point Loading) (C 78 - 39)

Test for Yield of Concrete (C 138 - 39), with a modification in Section 5 (*b*) changing "50" to read "25" and "100" to read "50" strokes.

The last five methods in the above list were approved for submission to letter ballot of the Society, subject to favorable letter ballot vote[26] in Committee C-9. This recommendation represented a change in the report as preprinted which had recommended the revised methods for publication as tentative.

Withdrawal of Tentative Standard:

Test for Soundness of Aggregates by Freezing and Thawing (C 137 - 38 T)

The paper by J. C. Pearson on "Volumetric Methods for Determining the Air Content of Freshly Mixed Concrete," appended to the report, was presented by the author.

Sanford E. Thompson Award

The chairman then introduced Sanford E. Thompson who presented the Sanford E. Thompson Award. The award was established in 1938 by Committee C-9 in honor of the first chairman of the committee, and as an annual token of recognition to the author of a paper presented before the A.S.T.M. and considered of outstanding merit. The purpose of the award was also to encourage research and investigations that extended the knowledge of concrete and concrete aggregates.

---

[26] These recommendations, not preprinted, were accepted by unanimous consent, subject to favorable letter ballot of Committee C-9, which ballot has been favorable and the results are given in the report of the committee, see p. 341.

Mr. Thompson then announced that the Sanford E. Thompson Award had been made to Douglas McHenry, Engineer, Bureau of Reclamation, U. S. Department of the Interior, for his paper on "A New Aspect of Creep in Concrete and Its Application to Design," presented at the 1943 Annual Meeting.

In accepting the certificate of the Sanford E. Thompson Award, Mr. McHenry expressed sincere appreciation of the recognition and honor conferred.

Papers:

The following papers were presented:

A Comparison of Results of Sieving Procedures in Soundness Tests on Maine Sands—Andrew Adams and Horace A. Pratt, presented by H. W. Leavitt.

Application of Flay Ash for Lean Concrete Mixes—Harry A. Frederick, presented from manuscript by the author.

Entrained Air—Its Effect on the Constituents of Portland Cement Concretes—Henry L. Kennedy, presented by the author.

FIFTEENTH SESSION—CONCRETE—(*Continued*)

FRIDAY, JUNE 30, 9:30 A.M.

SESSION CHAIRMAN: ALEXANDER FOSTER, JR.

Papers:

The following papers were presented:

Precision Indices for Compression Tests of Companion Concrete Cylinders—S. P. Wing, W. H. Price, and C. T. Douglass, presented from manuscript by Douglas McHenry.

The Measurement of Concrete Strength by Embedded Pull-Out Bars—Bailey Tremper, presented by Stanton Walker.

Some Properties of Concrete Under Sustained Combined Stresses—C. M. Duke and H. E. Davis, presented by Douglas McHenry.

Tests Comparing the Modulus of Elasticity of Portland-Cement Concrete as Determined by the Dynamic (Sonic) and Compression (Secant at 1000 psi.) Methods[27]—T. E. Stanton, presented from manuscript by H. F. Gonnerman.

The Effect of Discontinuities on the Natural Frequency of Beams—Philip G. Kirmser, presented by the author.

SIXTEENTH SESSION—NON-FERROUS METALS AND ALLOYS (*Continued*)

FRIDAY, JUNE 30, 9:30 A.M.

SESSION CHAIRMAN: PRESIDENT DEAN HARVEY

Committee B-2 on Non-Ferrous Metals and Alloys:

Report, not preprinted, in the absence of the chairman, presented from manuscript by J. L. Christie.

Committee B-7 on Light Metals and Alloys, Cast and Wrought:

Report presented by Sam Tour, chairman, and the following actions taken:

Accepted as Tentative, Revisions in:

Spec. for Aluminum Sheet and Plate (B 25 - 43 T)

Spec. for Aluminum-Base Alloy Sand Castings (B 26 - 43 T), omitting "to the nearest 1000 psi." and "to the nearest 1 per cent" from Table I; also retain requirements for alloy S2 but change zinc to 0.3 per cent max.

Spec. for Aluminum-Alloy (Duralumin) Sheet and Plate (Aluminum-Copper-Magnesium-Manganese) (B 78 - 42 T)

Spec. for Aluminum-Manganese Alloy Sheet and Plate (B 79 - 43 T)

Spec. for Magnesium-Base Alloy Sand Castings (B 80 - 41 T), except for the proposed changes in Table I as preprinted which were withdrawn by the committee

Spec. for Aluminum-Alloy (Duralumin) Bars, Rods, Wire, and Shapes (Aluminum-Copper-Magnesium-Manganese) (B 89 - 42 T)

Spec. for Magnesium-Base Alloy Sheet (B 90 - 41 T)

Spec. for Magnesium-Base Alloy Forgings (B 91 - 41 T), except that the proposed changes to delete alloys 15, 15X, 15A, 15XA, 18 and 18X were withdrawn by the committee

---

[27] Published in ASTM BULLETIN, No. 131, December, 1944, p. 17.

- Spec. for Magnesium-Base Alloys in Ingot Form for Sand Castings and Die Castings (B 93 - 41 T), except for the changes in Table I, excluding that in alloy 13X, which were withdrawn by the committee
- Spec. for Magnesium-Base Alloy Bars, Rods, and Shapes (B 107 - 41 T), except that the proposed changes to delete alloys 15 and 15X were withdrawn by the committee
- Spec. for Aluminum-Base Alloy Permanent Mold Castings (B 108 - 43 T), omitting "to the nearest 1000 psi," and "to the nearest 1 per cent" in Table IX; also retain requirements for alloy S2 but change zinc to 0.3 per cent max.
- Spec. for Aluminum-Magnesium-Chromium Alloy Sheet and Plate (B 109 - 43 T)
- Spec. for Aluminum-Manganese Alloy Sheet and Plate for Use in Welded Pressure Vessels (B 126 - 43 T)
- Spec. for Aluminum Sheet and Plate for Use in Welded Pressure Vessels (B 178 - 43 T)

Accepted as Tentative:

Spec. for Aluminum-Base Alloy Die Castings, to replace Standard B 85 - 42, with the following changes:[28]

(1) In Table I on Chemical Composition, delete the reference to Alloys VI, VIII, IX, XI, and XII, as these alloys are considered obsolete.
(2) Designate the present Alloy V as Alloy V-A and add to Table I on Chemical Composition requirements for Alloys V-B and LXXIX-B.
(3) Change the composition for the alloys included in Table I to agree with the values shown in the accompanying Table IV.
(4) Add a statement reading that alloys IV, V-A, VII-A and LXXIX-A are suitable for die casting either in gooseneck or cold chamber machines and that Alloys V-B, VII-B and LXXIX-B may be die cast only in cold chamber machines.
(5) Designate the alloys in accordance with the recommendations of Committee B-7, as follows:

Alloy No.	New Designation
IV	S4
V-A	S5
V-B	S7
VII-A	SC2
VII-B	SC1
LXXIX-A	SC6
LXXIX-B	SC5

TABLE IV.—CHEMICAL REQUIREMENTS.

Alloy	Former Alloy No.	Copper, max., per cent	Iron, max., per cent	Silicon, max., per cent	Manganese, max., per cent	Magnesium max., per cent	Zinc, max., per cent	Nickel, max., per cent	Tin, max., per cent	Other Constituents, max., (Total), per cent
S4	IV	0.6	2.0	4.5 to 6.0	0.3	0.1	0.5	0.5	0.1	0.2
S5	V-A	0.6	2.0	11.0 to 13.0	0.3	0.1	0.5	0.5	0.1	0.2
S7	V-B	0.6	1.3	11.0 to 13.0	0.3	0.1	0.5	0.5	0.1	0.2
SC2	VII-A	3.0 to 4.0	2.0	4.5 to 5.5	0.5	0.1	1.0	0.5	0.3	0.5
SC1	VII-B	3.0 to 4.0	1.3	4.5 to 5.5	0.5	0.1	0.6	0.5	0.3	0.5
SC6	LXXIX-A	3.0 to 4.0	2.0	7.5 to 9.5	0.5	0.1	1.0	0.5	0.3	0.5
SC5	LXXIX-B	3.0 to 4.0	1.3	7.5 to 9.5	0.5	0.1	0.6	0.5	0.3	0.5

Adopted as Standard:

Spec. for Aluminum Ingots for Remelting (B 24 - 41 T)

It was announced that the proposed revisions appearing in the preprinted report in the Tentative Specifications for Aluminum-Base Alloys in Ingot Form for Sand Castings (B 58 - 42 T) and for Aluminum-Base Alloys in Ingot Form for Permanent Mold Castings (B 112 - 41 T) had been withdrawn by the committee.

Committee B-6 on Die-Cast Metals and Alloys:

Report presented in the absence of the chairman, by the chair, and the following actions taken:

(6) Make the necessary editorial changes in the text to provide for the procurement of both gooseneck and cold chamber castings.
(7) Revisions in the table of physical properties.

If the above recommendation is accepted, the withdrawal of Emergency Alternate Provision EA - B 85a will be recommended through Committee E-10 on Standards.

Accepted as Tentative, Revisions in:

Spec. for Magnesium-Base Alloy Die Castings (B 94 - 40 T)

Adopted as Standard:

Spec. for Lead- and Tin-Base Alloy Die-Castings (B 102 - 39 T)

---

[28] This recommendation, not preprinted, was accepted by unanimous consent, subject to favorable letter ballot of Committee B-6, which ballot has been favorable and the results are given in the report of the committee, see p. 262.

Committee B-8 on Electrodeposited Metallic Coatings:

Report presented by R. J. McKay, chairman, who called upon H. A. Pray to present the report of Subcommittee II on Performance Tests

Papers:

The following papers were presented:

Micro-Deformation Under Tension and Compression Loads of Thin Aluminum Alloy Sheets for Aircraft Construction—Georges Welter, presented by title.

Short Time Tests of Solders and Soldered Joints—J. A. Kies and W. F. Roeser, presented by Mr. Kies.

A Numerical Rating Method for the Routine Metallographic Examination of Commercial Magnesium Alloys[29]—P. F. George, presented by the author.

There being no further business, the Forty-seventh Annual Meeting adjourned *sine die.*

August, 1944.

---

[29] Published in ASTM BULLETIN, No. 129, August, 1944, p. 35.

THE ART OF BEING A MATERIALS ENGINEER

ANNUAL ADDRESS BY THE PRESIDENT

DEAN HARVEY[1]

JUNE 28, 1944

In reviewing the annual addresses by the Presidents of our Society, I have been impressed with the valuable information given on the properties and the testing of materials. This, of course, is what we would expect, since it is our field of work. I do not find so much reference, however, to the man who is responsible for obtaining the results—to the engineer, the chemist, and the tester—as to how he may become more effective in his work. I believe that it will be profitable for us briefly to consider some of the factors which have to do with our effectiveness as technical men and women and as members of the American Society for Testing Materials.

Our civilization has become so highly developed and the results so astounding, we do not pause to think that it rests upon the efforts of the individual and his ability to imagine and to bring into reality his dreams. Man is the source of all progress and, therefore, is of more importance than any of his creations.

My subject this evening, therefore, is "The Art of Being a Materials Engineer," considering under this category persons who are engaged in work on materials.

First, I should like to review with you a few of the characteristics which are important to all of us.

Cooperation:

Cooperation perhaps should be given first place. Without it the technical man has to depend upon his own efforts, but with the aid of others his resources are multiplied many times.

The history of the development of knowledge provides many illustrations of the power of cooperation.

In the ancient world, there was little direct exchange of ideas between the few and widely scattered men who were contributing to the sum of knowledge. Under these circumstances, it required a long time to develop the main principles of mathematics which are the foundation of science, and to make application of them.

In the Dark Ages, the ruling powers demanded that the so-called scientific knowledge handed down from the past be accepted as inviolable even though some of these conceptions were already being questioned by some inquiring minds. You will recall the famous controversy in which Galileo was involved, in which he finally was obliged to withdraw his statement that the earth was round and admit that it was flat. Investigators had to work in secret, under pain of severe punishment for criticising any established beliefs.

Later years, however, eventually brought freedom from these restrictions, beginning with The Renaissance, and from that time on we learn of scientists in

---

[1] Materials Engineer, Engineering Labs. and Standards Dept., Westinghouse Electric and Manufacturing Co., East Pittsburgh, Pa.

Europe writing to each other, comparing notes on their experiments and theories. The correspondence between Newton and Leibnitz on mathematics is famous.

Slowly, the collaboration between scientists led to organized cooperation. Learned societies were formed in Italy, France, Germany, and England for the exchange of ideas and experimental data. The increase and the spread of knowledge became much more rapid when men shared with each other their ideas. Modern industry is based on the cooperative efforts of men.

Cooperation along engineering lines in this country also was slow in developing. Persons in charge of manufacture or other construction work made rule-of-thumb application of such basic scientific knowledge as was available, but there was no cooperative effort to establish engineering principles. The organization of the first American national engineering society, the American Society of Civil Engineers, in 1852 was a noteworthy event. Other societies, such as mechanical, electrical, and chemical followed. The A.S.T.M. was established in 1902. The development of American industry was enormously accelerated when these engineering bodies took up the standardization of equipment and testing.

The term "cooperation" is very broad indeed. It is the working together of individuals on a common problem. In working together, obviously, it may be necessary for each to make some concessions in order to arrive at a common result. Many persons do not realize this. Compromises are especially important in connection with standardization work. But the giving up of certain ideas in order to obtain agreement is more than offset by the advantage of having a standard practice to be used by all.

Furthermore, in association and cooperation while each person makes a contribution, he receives from the contributions of others much more in return than he gives.

Enthusiasm:

One of the most important characteristics of any successful worker is interest in his work. This may seem obvious, but all of us remember instances where someone has not been interested and, as a result, has done his work in a careless and incomplete manner.

The word "enthusiasm" comes from the Greek, meaning "god in us;" that is, inspired of the gods. This inspiration truly seems to be a divine gift. We remember with pleasure persons who have had this divine inspiration and have accomplished great things because of their devotion to their task. The least that each of us can do is to take a definite interest in our work and endeavor to carry it forward effectively. If, in addition, we have this divine touch and pursue our work with enthusiasm, we shall be marked men or women.

Communicating Our Ideas:

One of the most important requirements for the technical man carrying on the type of work represented in our Society is to be able to express his thoughts clearly and concisely by the spoken or written word. It is not sufficient for a man to have ideas. He must be able to transmit those ideas to others or they cannot be fully put into operation.

An adequate vocabulary is essential. This does not necessarily mean a very large vocabulary, but large enough to include the words which will enable us to convey our thoughts completely and accurately. Each line of work has its own vocabulary which constitutes an important tool that is needed just as much as the testing machines. It includes the words required to express the finer shades of meaning which sometimes are necessary for accuracy, just as we need precision machines.

A vocabulary may be acquired by reading and by practice in writing. Correct writing involves a working knowledge of grammar and rhetoric and also of the meaning of the words used. It is important, particularly in the engineering field, that words be used accurately. The selection of a word with just the right shade of meaning insures the correct interpretation whereas an inaccurate word is likely to give the wrong impression. It has been stated that a man's thoughts are limited by the extent of his vocabulary, as he cannot formulate ideas unless he can connect them with definite words describing them. Certainly, at least, there is a large element of truth in this statement; a man without an adequate vocabulary for his needs certainly is handicapped.

Loyalty:

Loyalty is considered by many to be the greatest human virtue. We all know of instances where the loyalty of a man to a friend, to his organization, or to a cause, is outstanding. It is commentary on most of us that such cases are so uncommon as to attract attention. I am not speaking now simply of favorable interest but of real faithful devotion.

Loyalty is just as important in our business life as it is in our personal affairs. Most of us probably could give a greater measure of devotion to the company with which we are connected and also to our engineering society. Fortunate is the man who has a devoted friend and just as fortunate is the organization which receives devoted service from its members. I am glad to say that the A.S.T.M. has many devoted members.

Contacts:

Man is a gregarious animal; that is, he seeks the association of his fellows. We are so accustomed to this association that we do not stop to think how much it means to us. We receive infinitely more from others than we contribute.

Much of this comes to us casually, but especially in our technical work much more can be gained with a little careful attention. As a man advances and begins to make independent decisions, he finds that more and more of his time must be devoted to keeping informed on what is going on. Even a chance remark overheard may open up new possibilities of great importance.

How may we keep open the channels through which comes valuable information such as this in the field of materials and testing? Technical journals in the field of materials and their applications are important factors. Association with other persons familiar with the work, both as producers and consumers, provides much information not given in the magazines, and gives an opportunity to discuss personal problems.

Membership in at least one national engineering society carefully chosen so as to deal most directly with our problems is truly a necessity. The A.S.T.M. constitutes the best source of information and personal contacts with reference to materials and testing of any of the national bodies. The papers on materials and testing presented before the Society at its annual and the district meetings are timely and authoritative. These meetings and those of the standing committees on standardization work also provide valuable contacts with many of the best technical minds on materials.

In 1931, I read an editorial on the subject of "Change with Change," which is just as timely today. It said, in part:

"Every man likes to think of his

business as a permanent thing, whose problems, once solved, will stay solved. Here are just a few of the familiar sweeping changes in demand recently.

"The rise and decline of pee wee golf.

"Pajamas, short skirts, bobbed hair and the rise of the barber and beauty specialist.

"The effect of alloy steels on machine-tool design, and of welding and new materials on product design.

"Product and market study are as necessary a part of a business as the plant or the bank account. Particularly are alertness and flexibility necessary to meet the developments which are almost sure to follow our emergence into a new business cycle."

Keeping abreast of the times involves suitable contacts to bring us the current information, and the necessary flexibility to utilize it promptly.

Characteristics for Different Classes of Work:

The characteristics essential or desirable for the technical man engaged in work on materials differ, depending upon the branch of work in which he is engaged, that is, whether he be (1) a research engineer or scientist, (2) a laboratory technician, or (3) a so-called materials engineer, using the latter term in its more restricted sense.

Research Engineer or Scientist

The outstanding characteristics of the research engineer or scientist are many:

1. An insatiable curiosity about physical phenomena, material, and testing.

2. A keen sense of observation. Many an important discovery has resulted from observing a peculiar phenomenon which had escaped the observation of others. The discovery of penicillin is a recent example. Dr. Alexander Fleming in one of his experiments in bacteriology noted a distinct anti-bacterial effect of a mold which had spoiled one of his cultures. Further investigation showed that the liquid made from this mold was the best treatment for many of our most deadly infections.

3. Analytical ability to interpret properly the observed phenomena, mathematically or otherwise.

4. Inventive ability.

5. An interest in and knowledge of methods of measurement (in common with other testing work.)

6. Optimism and continued enthusiasm. If it were not for them most projects would be abandoned before the difficulties were overcome.

7. Cooperative ability. In most cases the aid of specialists in allied fields is required.

8. The ability to stick to the main objective. It is easy to wander off into interesting but unprofitable byways.

9. The ability to arouse interest and enthusiasm in others. Often a most difficult problem is to get others to recognize the significance of his work and to take suitable action.

10. Intellectual honesty.

Laboratory Technician:

The characteristics of the laboratory technician may be enumerated:

1. A thorough knowledge of methods of measurement (instrumentation).

2. Carefulness and accuracy, together with the ability to keep neat, complete, and concise records.

3. Ability to write reports which will include the essential data, are accurate and readily understood.

4. Ingenuity in devising new or modified test methods to enable him to adapt the tests so as to determine the desired properties.

5. Honesty in observing and reporting results.

6. A preference for using his hands rather than doing desk work.

7. A willingness to do routine work, as there will be much of it.

8. A willingness to accept instructions and orders, since laboratory work is largely a service function. Sometimes the instructions may seem unnecessary and even foolish, but there may be a good reason for them.

Materials Engineer:

The individual commonly characterized as "materials engineer" is responsible for the specifying and the application of materials. He should have the following attributes:

1. An ability to grasp and a willingness to grapple with all manner of detail.

2. Carefulness. Accuracy in details is a prime requisite.

3. An ability to evaluate and interpret test results.

4. A knowledge of industrial processes of manufacture.

5. An appreciation of the need for standardization of materials, specifications, and methods of testing. A knowledge of existing standards is almost a prerequisite.

6. Ability to recognize the vital points in a problem.

7. Good judgment, drawing conclusions only upon sufficient evidence.

8. An inquisitive and observant mind, but not necessarily of the inventive type.

9. A good personality, willing to cooperate and having the ability to coordinate results so as to obtain agreement between conflicting ideas and personalities. He will have many dealings with other persons on the requirements and application of materials.

10. Ability to write and speak clearly, concisely and accurately, giving all necessary information. The writer of specifications needs a good working knowledge of grammar, including punctuation, as the interpretation of specifications often depends upon the exact wording used, and upon the punctuation.

11. Ability to listen (just as important as the ability to talk).

12. Above all, the materials engineer should be a person of vision who can take advantage of any improvement in processes or materials and have the ability to appraise the application of these materials.

SOME CONSIDERATIONS IMPORTANT TO THE TECHNICAL WORKER

Let us now review some phases of the work on materials which should receive the attention of the technical worker.

Utilizing Available Information:

When any project is to be undertaken, the first, and very important operation is to ascertain what knowledge already is available on the subject. An essential part of the library should be indexes of articles relating to the work in question. Public technical libraries, or the libraries of the engineering societies and frequently engineers' clubs, have valuable indexes, as well as the publications themselves, on a wide variety of technical subjects.

Recently, a friend of mine inquired of another with reference to a problem that he was about to investigate, involving considerable testing. He was told that there was an excellent article on this subject in the A.S.T.M. *Proceedings* a few years before. The next time they met, this man thanked him for the information, saying that it had solved his problem and he found it unnecessary to carry out any further work on the subject. Many other illustrations could be given where technical information already available has either solved the problem or given a good start to the investigation.

In addition to searching the literature, it is advisable to find out what other groups have done. For instance, if we are concerned with some work involving coat buttons, we should find out what the "Coat Button Committee" (or Society) has done on the subject. Too often other groups have started work which our Society already was carrying on, or even had completed.

The Preparation of Specifications:

Since the preparation of satisfactory specifications for materials and the development of suitable methods of evaluating properties are important problems with which many materials engineers are confronted, it is appropriate to record some thoughts on these subjects.

As in other types of writing, specifications have their own peculiar style, particularly adapted to the purpose for which the specifications are to be used. The purchase specification has the important function of giving all of the interested persons the same understanding of the requirements to be met:

(a) The purchasing agent uses it as complete information in ordering.

(b) The manufacturer receives from it information needed to enable him to manufacture the material.

(c) The inspector follows it as a guide in determining whether the material has the required properties, following the prescribed methods of sampling and testing, thus avoiding either too lax or too rigid inspection.

(d) The design engineer receives from it information as to the properties which he may expect in the material.

These several uses must be kept in mind in the preparation of the specifications, so that misunderstandings, confusion, and delays will be avoided. The following considerations should be borne in mind:

1. A specification must describe the requirements to be met so clearly that they cannot be misunderstood. This demands clear statements, logically arranged. For material specifications, the standard form adopted by the A.S.T.M. is excellent and is being very extensively used.

2. Brevity is a cardinal virtue, and the specification should be as concise as possible, consistent with clarity and completeness.

3. In the selection of materials, commercial grades are preferable to special grades, as they usually are most readily available, their production has been carefully standardized so as to provide a more uniform quality than is obtained with special materials, and being manufactured in larger quantities, the cost is likely to be less than that of other materials of similar quality.

4. Similarly, standard specifications, such as those prepared by the A.S.T.M. for commercial grades of materials should be used wherever practicable. Since both producers and consumers have participated in the preparation of A.S.T.M. specifications they are acceptable to both. Their requirements have been worked out with great care. If incorporated in a general specification, there is a distinct advantage in using the standard paragraphs covering the requirements for quality, exactly as written, as they have been found by experience to be satisfactory.

5. It often is advisable to include methods of sampling for test, in order to insure obtaining representative samples.

6. The methods of test usually should be given in detail unless the test is one which has been established as standard practice in the industry. As in the case of specifications it is desirable to use standard methods of test, if available, such as those prepared by the A.S.T.M.,

for these have been carefully worked out and accurately described. Even what may appear to be a small and unimportant difference in the method of making a test may cause a significant difference in the test results obtained. Therefore, it is important that tests by producers and consumers be made exactly in the same way so that results are comparable.

7. The primary interest of both the producer and the consumer is in the performance of the material in service. Emphasis, therefore, should be placed upon the performance whenever practicable rather than upon the chemical composition, construction, or method of manufacture. It is desirable to give the manufacturer the greatest possible latitude to furnish material suitable for the desired application. By doing so he is given the opportunity to furnish the material best adapted for the purpose and sometimes at a reduction in price.

8. A common fault in preparing specifications is to make them too drastic. The properties specified for the material should be those that will render it satisfactory for the intended application. Unnecessarily severe requirements are to the disadvantage of both the producer and the consumer, tending to delay production, increasing the cost, and in some cases limiting the supply. It is especially important to use the standard commercial tolerances for dimensions where possible. Shop practice is based upon standard tolerances and the closer limits are likely to be difficult to obtain.

Methods of Testing:

The importance of methods of test in connection with our work on materials is not always fully appreciated. The only way to obtain accurate information about the properties of materials is to test them. As I have already pointed out the values obtained by test depend upon how the test is made, and in many cases a difference in the test procedure which seems slight and unimportant may cause significant differences in the results obtained. In order to be able to compare the results of tests made in different laboratories, it is necessary that the tests be made in exactly the same way. The need for standard methods of test, therefore, is apparent.

The standing committees of our Society have done an outstanding work in preparing many standard methods of test for a large variety of materials. These test methods have been prepared with great care to determine accurately the desired property and so as to obtain reproducible results. They should be used in all cases where they apply.

For convenience, tests may be divided into two classes:

First, acceptance tests. They are called for in the specification to determine whether the material conforms to the requirements specified. These tests preferably should indicate whether the material will provide the performance required in service. Sometimes it is not practicable to use a performance test for acceptance when it is unduly long or complicated, and sometimes we do not know how to make a test on the material which will clearly indicate performance. In such cases, after the material has been found suitable for the application, it is necessary to specify other tests which will control the properties of the material so as to insure that it will be of the quality that has been found satisfactory.

The second class consists of the tests made to obtain information regarding the properties of the material, and may include tests made under various conditions such, for instance, as the properties at different temperature. These tests aid in the selection of materials for specific applications by giving their properties which have a bearing upon their performance. They do not necessarily have to be tests that can be made quickly, but may require considerable time and, perhaps, more complicated equipment than would be practicable for an acceptance test.

With both classes of tests it is necessary for us to be able to judge the meaning of the test and to interpret the significance of the results obtained.

It is advisable for the materials engineer to make a study of the tests he is using so as to have a clear understanding as to what they mean in terms of the various properties of the material and also in relation to its application. This is not always so easy. Our Society has recognized the necessity for an understanding of the meaning of the various tests and has published considerable information of value along this line both as formal reports or as individual papers discussing the tests as applied to various materials. Many of the standing committees are actively at work on this important subject.

Interpretation of Test Data:

In the testing of materials it may be said that the results obtained will be no better than the sampling will permit. That is, the sampling of the lot of material determines to a considerable extent the degree of reliability of the test. If, for instance, several non-homogenous lots of materials are mixed, such as apples, potatoes and carrots, and a sample is taken, that sample will not be necessarily representative of the entire mixed lot as it may consist only of apples.

The subject of sampling is too involved a question to be discussed here, so I will refer you to the excellent articles which have been written on this subject. I simply wish to call your attention to its importance.

The excellent "Manual on Presentation of Data" sponsored by our Committee E-1 on Methods of Testing gives the principles involved in this subject and recommends practices to be followed. It describes means for condensing the information contained in a set of observations and presenting the essential information in a concise form more readily interpretable than the unorganized mass of original data. While this is accomplished by statistical methods usually avoided by the average technologist, the procedure may readily be understood with a little study. It is very desirable for us to become acquainted with the basic principles involved in the effective presentation of data. In addition to enabling us to present the results of our tests, it also gives us a basis for determining whether the sampling and testing have been done in such manner as to give us reliable data.

The question of the number of tests to be made is an important consideration. Committee D-13 on Textile Materials has prepared for the guidance of its members a "Recommended Practice for Calculating the Number of Tests for Determining the Average Quality of a Textile Material." The number of tests to be made upon a lot of material is important as it determines the degree of accuracy with which the test data represent the lot of the material tested.

The National Societies:

I have already briefly mentioned the valuable contacts which the national engineering and scientific societies offer to the materials worker. These societies are making a great contribution to industry and to its technical men individually.

In reviewing the scope and activities of these organizations, I find a fundamental similarity, but a distinct individuality for each. They have had a large part in the development of their respective industries.

Their means of accomplishing their objectives are well expressed in the constitution of The American Society for

Mechanical Engineers from which I quote as follows:

1. Holding meetings for presentation and discussion of original papers.

2. Publishing papers and reports and disseminating knowledge and experience of value to engineers.

3. Developing and promulgating standards, codes, and recommended practices.

4. Encouraging engineering research tests and other original work.

5. Encouraging intercourse among engineers for the mutual exchange of knowledge and experience.

The technical sessions of these societies and their local section meetings throughout the country are of great value in disseminating information and in affording their members the opportunity to present and discuss technical papers and to become acquainted with their fellows.

Their standardization programs have been especially valuable in concentrating production on standard types and sizes, reducing the large variety of materials, parts, and equipment to the smaller number of sizes and capacities most needed, and also in the development of standard methods of test and recommended practices.

The technical man will do well to determine the society most helpful in his work and become affiliated with it. He should take part in its activities, for the benefits he receives will depend to a considerable extent upon his interest and upon the contributions which he makes. That which he gives will be small in comparison with the profit he obtains from this association, for his contribution is that of one person or organization, while that which he receives may come from the entire membership. There will also be a satisfaction derived from his association, with pleasure in the acquaintances he makes and some warm friendships.

Likewise, it is well for a company to encourage its men to participate in the national engineering society activities, and to hold a company membership where this is possible. This brings to the company up-to-date information on the progress of events in its field of activity and also provides the opportunity to partiicipate in standardization work which produces much larger results by the cooperative effort than can be obtained in any one company. Also, opportunity is given for cooperative research, bringing results which a smaller company could not afford to develop in its own organization.

These remarks include only a very small portion of what might be said to advantage on the subject of our personal efficiency and usefulness as technical men and women engaged in work on materials. While they are quite incomplete, it is my hope that they will serve to stimulate our thoughts so as to aid us in doing a better job.

None of us, I am sure, has become as proficient as he might in "The Art of Being a Materials Engineer." We have a great field in which to work; it is developing rapidly in many directions, giving us increasingly larger opportunities. We also have the great privilege of association with our fellows in the A.S.T.M. There is no better fellowship or Society than ours.

We are all partners in the great enterprise of making this world a better place in which to live. This includes our own personal relations with each other, our duties as citizens, our activities in our respective companies, and our association together in the A.S.T.M.

It behooves us occasionally to take account of stock, and see how we can improve our performance.

We have received a great heritage from our fathers, and it is only right that our sons and daughters should expect an even better bequest from us.

ANNUAL REPORT OF THE EXECUTIVE COMMITTEE

For the third successive year the Executive Committee presents its report to the Society with our country engaged in war—total war in every sense of the term. That such a war would have a profound effect upon the operations of this Society is obvious; but it is with a sense of gratification and pride in the accomplishments of the Society that the Executive Committee can report that all essential activities have not only been carried on but intensified as an aid to war production and the conservation of materials and resources. Some things of lesser importance to the war effort have been minimized or temporarily discontinued; emphasis has been upon those things the doing of which will contribute in one way or another to the winning of the war. Many of these latter will be obvious from the news of Society affairs in the ASTM Bulletin, from the reports and papers at this meeting, and from the technical publications. Only a few of the accomplishments of the past year will be mentioned in this report.

It may be well to refer to the statement of war-time policy given in the report a year ago, under which the Society has been operating since Pearl Harbor, namely, to make available all of the Society's facilities to assist the Government and industry in dealing with any problems within our traditional field of engineering materials. It can be said in brief that this policy has been intensively pursued this year along the lines discussed in earlier reports and that no effort or expense has been spared to give assistance to either Government or industry. Meetings have been held to develop and disseminate knowledge of materials, and publications covering those meetings have been printed as expeditiously as possible, often in the face of discouraging printing and binding difficulties. New specifications and methods of testing have been developed, and existing ones brought up to date for the 1943 Supplements to the Book of Standards and the several compilations of standards. The emergency alternate provisions and emergency specifications have continued to demonstrate their war-time value, and it is worthy of note that even after the intensive emergency work of 1942–1943, during this past year there were 21 new emergency alternates issued and 19 revised, 9 new emergency specifications issued and 4 transferred to tentative status, resulting in a total of 123 emergency alternates and 35 emergency specifications now in effect.

The Society has continued to cooperate with the Federal specifications committees, the various bureaus and departments of the War and Navy Departments, the War Production Board, and other Governmental agencies. Among the activities involved might be mentioned: Continued collaboration, especially through Committee A-1 on Steel and many of its members, with the National Emergency Steel Specifications project of WPB, of which the Secretary-Treasurer until recently was administrator; the development of hardness conversion tables for steel; continued activity on specifications for copper-base wrought and cast products, solders and bearing metals; specifications for special control quality aluminum-base alloy die-castings; new specifications for electrodeposited coatings of lead on steel; revised specifications for rubber and synthetic rubber compounds for automotive applications, and various specifications for such rubber products as hose, belts, gaskets, and cellular products, all of particular military significance; continued work in the development of urgently needed tests and specifications for various types of plastics, supplementing the activities reported a year ago; development of specifications and grading for mica, which has been one of the more critical minerals; information covering mildew resistance of textiles, resistance of fabrics to insects, and the value of mothproofing treatments, etc.; emergency provisions for soap and detergents specifications to aid in the conservation of various critical chemicals.

An accomplishment of special interest was the development at the request of the Ordnance Department of a method of test for color of U. S. Army motor fuel. This was done under the auspices of Committee D-2 on Petroleum Products and Lubricants by developing an aqueous solution of inorganic salts possessing the desired colorimetric characteristics, certified by the National Bureau of Standards, which provides a comparison standard for either laboratory or field use. An emergency method, ES - 32, was issued only three months after the request was received; and although outside of its usual line of activity the Society at the request of the Ordnance Department has undertaken the marketing of this color standard to the Government and industry at cost.

Various committees and members of the Society have been able to contribute helpfully in War Production Clinics sponsored by WPB, two of which are noted later in this report.

What has been said so far deals primarily with the value of the Society's output—standards, reports and other publications—to the prosecution of the war, and the Executive Committee feels that the record is one in which the Society can take much pride. However, no reference to the Society's contribution would be complete without mention of the fact that many members of the Society are serving either in the Armed Forces, in some agency of the Government or in industry in important and key capacities. Committees of the Society have on frequent occasion given advice and comment on materials problems and some have carried on special studies to ascertain facts and determine information that will be of help. The Society has responded to many requests for information and copies of publications.

For most of the past year the Secretary-Treasurer has continued his services in the War Production Board. It was evident after the annual meeting in 1943 that the growing pressure and importance of the work of the Society would require that he devote a greater proportion of his time to it, so that effective September 1, 1943, he resigned as Chief of the Materials Branch of the Conservation Division, WPB, but continued as Chief of the Special Consultants Staff reporting to the Director of the Conservation Division. He devoted his time mainly to administrative and consulting services on specifications and construction materials, and to his responsibilities for the National Emergency Steel Specifications project. About a third of his time was devoted to that work. It has now become necessary for the Secretary-Treasurer to devote his entire time to the affairs of the Society; he therefore resigned from the War Production Board effective May 31, 1944. The close cooperation of the Society and the WPB on specification matters is being maintained from Society Headquarters. This cooperation is further fostered through the appointment of President Harvey as Chief of the Special Consultant Staff.

Believing that it is just as important to keep the Society's specifications consistent with improving as well as depreciating conditions with respect to the supply of critical and strategic materials, and realizing that in many places the need for conservation of materials and resources has been largely alleviated, the Executive Committee has directed all standing committees to review the emergency alternate provisions and emergency standards within their jurisdiction and report to this annual meeting their recommendations for continuance or cancellation of such emergency provisions and standards or, if desired, their transfer to tentative or standard status. Experience in recent months has indicated the need of the emergency procedure, but at the same time materials developments have just as clearly indicated that we no longer need some of the emergency provisions that were so necessary a year or two ago. The Executive Committee feels that the emergency procedure should be used only where there is a real emergency, and a statement of policy will be formulated after a review of the reports of the standing committees referred to above.

Special Study Committee.

The foregoing section of the report touches upon the war activities of the Society. With it all, however, the Executive Committee—again referring to statements made in its report a year ago—is giving careful thought to the planning and carrying out of everything of fundamental importance to the welfare of the Society—for a sound, virile organization is essential at all times and especially so as we face a future that assuredly will involve many post-war and peace-time economic adjustments and, as can already be seen, will introduce many important changes in materials and their applications of great significance to the Society. After many discussions along these lines the Executive Committee has called to its aid the services of a Special Study Committee which it has appointed to review the activities of the Society critically and objectively, to examine and appraise all phases of its work in order to determine whether the Society is organized and functioning in the most effective manner best to serve its members, industry, and the nation at large now and in the years to come.

The committee consists of eleven members of the Society, each of whom has had extensive experience in one or more technical phases of the Society's work, as well as important executive and administrative responsibilities in the affairs of the Society. The committee is under the chairmanship of H. S. Vassar, Past-President of the Society; and the President and Secretary-Treasurer serve *ex-officio*. The personnel of the committee is as follows:

H. S. Vassar (chairman), Public Service Electric and Gas Co., Maplewood, N. J.
A. G. Ashcroft, Alexander Smith & Sons Carpet Co., Yonkers, N. Y.
P. H. Bates, National Bureau of Standards, Washington, D. C.
A. W. Carpenter, B. F. Goodrich Co., Akron, Ohio
T. G. Delbridge, Atlantic Refining Co., Philadelphia, Pa.
T. A. Fitch, Los Angeles Bureau of Standards, Los Angeles, Calif.
J. H. Foote, Commonwealth and Southern Corp., Jackson, Mich.
J. R. Freeman, Jr., American Brass Co., Waterbury, Conn.
F. E. Richart, University of Illinois, Urbana, Ill.
J. R. Townsend, Bell Telephone Laboratories, Inc., New York, N. Y.
E. W. Upham, Chrysler Corp., Detroit, Mich.

The Study Committee has been authorized to study any and all phases of the Society's work and to prepare comments, discussions, and recommendations related thereto. It has been suggested that some questions may profitably be considered with respect to three periods of time: war, transition, and peace; and that policies and plans might be developed for these periods, taking account of any over-all economic, technical, and scientific planning that may develop through Government, industrial, and technical agencies. The Study Committee will report directly to the Executive Committee.

Committee Activities:

Reports of committees for this Annual Meeting speak eloquently regarding committee activities during the year. Articles in recent issues of the ASTM BULLETIN have kept the members currently informed, and a review article planned for the next issue will summarize annual meeting activities. The current reports of Committee E-9 on Research and Committee E-10 on Standards deal with certain phases of committee work, hence this report will touch principally on new developments and certain administrative actions.

Among new developments are expansion of the Society's work into several new fields, namely, industrial aromatic hydrocarbons, metal powders and metal powder products, adhesives, and plywood and wood laminates.

A new Committee D-16 on Industrial Aromatic Hydrocarbons was organized in New York, N. Y., on October 26, 1943, under the following temporary officers: J. M. Weiss, John M. Weiss and Co., Chairman; C. A. Lunn, Consolidated Edison Co. of New York, Vice-Chairman; R. P. Anderson, American Petroleum Institute, Secretary. The scope of the committee is defined as: "Nomenclature, methods of test, and specifications for industrial aromatic hydrocarbons and related products boiling below 400 F. for other than fuel purposes"; the products covered include various grades of benzene, toluene, xylene, solvent naphthas, and similar hydrocarbon products. An account of the organization meeting and a list of the members appeared in the December, 1943, issue of the ASTM BULLETIN. Five subcommittees have been formed and the committee is already actively at work on its assigned task.

The field of powder metallurgy has come rapidly to the fore in the past several years. The great expansion in the use of metal powder products, notably for oil-less bearing applications but also in a host of other strategic places, was brought out in the Symposium on Powder Metallurgy at the 1943 Spring Meeting of the Society, and clearly showed the need for development of standard methods of test and specifications as applied both to the powders and the resulting compacts. Accordingly, the Executive Committee authorized the appointment of Committee B-9 on Metal Powders and Metal Powder Products with the following scope: "The formulation of specifications and methods of test for metal powder and metal powder products." The committee was organized in New York, N. Y., on February 22, 1944, and elected W. A. Reich, General Electric Co., as Chairman and W. R. Toeplitz, Bound Brook Oil-Less Bearing Co., as Secretary. An account of the meeting and the list of members appeared in the March, 1944, issue of the ASTM BULLETIN. Three subcommittees have been organized and work on the committee's problems is already actively under way.

The formation of a new Committee D-14 on Adhesives has been authorized by the Executive Committee with the following proposed scope: "The formulation of specifications, methods of test, and definitions of terms pertaining to adhesives, including synthetic resin adhesives and those derived from animal, mineral, and vegetable sources." The organization meeting will be held at Society Headquarters on June 20, 1944, under the temporary chairmanship of T. R. Truax of the U. S. Forest Products Laboratory. Some twenty years ago consideration was given to the Society's undertaking work on animal and other types of glues, but little interest was shown and the subject was not pursued. The development in recent years of various types of synthetic adhesives has stimulated interest in testing and specifications, and applications in such fields as plywood, laminates of various types, plastics, etc., have stressed the need for A.S.T.M. standards in this rapidly developing field. Opportunities for important accomplishments lie ahead of the new committee.

With respect to plywood and wood laminates, this important and rapidly developing field has been assigned to Committee D-7 on Timber with the understanding that the personnel of the committee will be suitably enlarged to include representative producers and consumers of these newer types of materials. In the field of laminates it is intended to include both wood- and wood-base laminates. The scope of the committee is also being expanded to include modified wood materials such as "impreg" and "compreg." A revised statement of scope is being discussed with the committee. Consideration is also being given to the status of the Society's work in the field of specifications and methods of test for materials that are used in the treatment of wood for such purposes as preservatives, waterproofing, fireproofing, and other similar modifying treatments.

The scope of Committee C-8 on Refractories has been slightly modified by authorizing the committee to engage in the formulation of "classifications" of refractories. The revised statement of scope reads:

> "The formulation of specifications, classifications, methods of test and definitions of terms pertaining to those materials generally considered to be in the field of commercial refractory products."

The scope of Committee E-4 on Metallography has been extended to provide for work on electron microscopic methods and electron diffraction methods, also the work on thermal analysis has been broadened to include all metallic materials instead of steels. The revised statement of scope reads:

> "Methods and technique of examination of all metallic substances by optical and electron microscopic methods and by X-ray and electron diffraction methods; methods and standards of measurement of grain sizes of and inclusions in metals and alloys; methods and recommendations for photography as applied to metallography; methods of thermal analysis of metallic materials; definitions of terms relating to metallography."

The Executive Committee is engaged in reviewing the status of certain committees in the Society that have been inactive, or less active than normally. It is recognized that while the war emergency has greatly stimulated the activities of most committees and especially those dealing with critical materials, it has interfered with the work of certain committees dealing with materials and products that have perhaps less significance just now. Nevertheless it is essential that the Society's committee organization be kept virile and active and considerable attention will be given during the coming year to these and other phases of committee activities.

District Committees and Meetings:

Several very interesting meetings have been sponsored by the various district committees, each of these being noted in the table of A.S.T.M. meetings on an adjoining page. Unquestionably the

A.S.T.M. MEETINGS JUNE, 1943–APRIL, 1944, INCL.

Meeting	Place	Date	Notes
Annual Meeting	Pittsburgh, Pa. William Penn Hotel	June 28–July 1, 1943	15 Technical Sessions 245 Committee Meetings (1452 Attendance)
Spring Meeting	Cincinnati, Ohio Netherland Plaza	March 2, 1944	Symposium on Applications of Synthetic Rubbers[a] (About 600 in attendance at each of the two sessions.)
A.S.T.M. Committee Week	Cincinnati, Ohio Netherland Plaza	February 28–March 3, 1944	148 Committee Meetings (745 Attendance)
District or Local (Sponsored by Groups in Cities Indicated)	Philadelphia, Pa.	September 23, 1943	Bristles from Casein[b] by T. L. McMeekin Acrylic Esters[b] by C. H. Fisher
	Philadelphia, Pa.	October 28, 1943	A Look at Life and Motion—featuring development of the ultraviolet microscope for use at high magnifications. Participating were Drs. F. F. Lucas (the microscope and its use); Mary B. Stark (cancer); J. F. Mahoney (venereal disease research—life history of the syphilis spirochete with motion pictures). (500 attendance)
	Detroit, Mich.	December 9, 1943	Symposium on Corrosion with three papers by Robert M. Burns,[c] E. H. Dix, Jr., and R. H. Brown[c] (600 attendance)
	Philadelphia, Pa.	December 16, 1943	Critical Instability by L. B. Tuckerman (100 attendance)
	Philadelphia, Pa.	February 22 and 23, 1944	Symposium on Plastics;[a] 15 technical papers; two sessions. (450 and 650 attendance, respectively; two informal dinners—125 at each)
	Northern California (San Francisco)	March 15, 1944	The Place of the National Engineering Society in Industry, by Dean Harvey General Activities of the Society by C. L. Warwick (125 attendance)
	Southern California (Los Angeles)	March 20, 1944	Textiles by Dean Harvey Specifications Work with the War Production Board by C. L. Warwick Grain Size Standards for Magnesium Alloys,[d] by C. H. Mahoney and A. L. Tarr (200 attendance)
	Chicago, Ill.	March 30, 1944	War Production Conference. A.S.T.M. Sponsored Panels on Standards and Specifications; joint sponsor of others including plastics and protective coatings
	Cleveland, Ohio	April 14, 1944	What of Engineering Materials in the Future by A. Allan Bates (140 attendance)
	Philadelphia, Pa.	April 20, 1944	Engineering Abroad, as Seen by Editors of "Engineering News-Record"—Waldo G. Bowman and Edward J. Cleary (85 attendance)
	Northern California (San Francisco) (Jointly sponsored by Structural Engineers Assn. of Northern California)	May 2, 1944	Portland Cement and the Distinctive Characteristics of the Five Different Standardized Types by P. H. Bates (125 attendance)

A.S.T.M. MEETINGS JUNE, 1943–APRIL, 1944, INCL.—Continued.

Meeting	Place	Date	Notes
District or Local (Sponsored by Groups in Cities Indicated)—*Cont.*	Southern California (Los Angeles)	May 8 1944	Cement and Concrete Standards and Their Application by P. H. Bates (200 attendance)
	Western New York—Ontario (Toronto) (Arranged by Affiliated Engineering and Allied Societies of Ontario)	May 9, 1944	Post-War Standardization,[e] J. B. Carswell Standardization in Canada by W. R. McCaffrey Contribution of the A.S.T.M. in the Field of Post-War Standardization by C. L. Warwick (250 attendance)

[a] Issued as a separate publication.
[b] Extended abstracts published in ASTM BULLETIN, No. 125, December, 1943, pp. 19 and 22, respectively.
[c] Published in ASTM BULLETIN, No. 126, January, 1944, pp. 17 and 21, respectively.
[d] Published in ASTM BULLETIN, No. 130, October, 1944, p. 15.
[e] Published in ASTM BULLETIN, No. 129, August, 1944, p. 15.

outstanding meeting was that in Philadelphia in February featuring a Symposium on Plastics held in two technical sessions on successive days in conjunction with which there were two informal dinners. Other notable meetings include the one in Detroit in January featuring three papers on corrosion; those on the West Coast in the Northern and Southern California districts at which the President and Secretary-Treasurer spoke; and while not a district meeting in the usual sense of that term, mention should be made of the extensive participation of the Chicago District Committee in sponsoring various panels in the War Production Clinic in Chicago in March. Probably the most unusual meeting was the one in Philadelphia in October on the general subject "A Look at Life and Motion" with leading world authorities on microscopy, cancer, and venereal diseases describing the applications of the ultraviolet microscope.

Another meeting of particular interest, although again not strictly a district-sponsored affair, was the one in Toronto on May 9 sponsored by the Affiliated Engineering and Allied Societies of Ontario covering the subject "Engineering Standards in the Post-War World." Arranged by O. W. Ellis, President of the Affiliated Engineering Group, who is also Vice-Chairman of the A.S.T.M. Western New York-Ontario District Committee, the meeting was the first in Canada in which the Society has participated. The Secretary-Treasurer, one of three speakers, discussed the subject, "Contributions of A.S.T.M. in the Field of Post-War Standardization." Col. W. R. McCaffrey, Secretary of the Canadian Standards Association, in his address detailed various Canadian problems, and J. B. Carswell, President of the Canadian War Assets Corp., dealt with the importance of post-war standardization to the engineer. A detailed writeup was published in the May ASTM BULLETIN, and Mr. Carswell's paper was published in the August BULLETIN.

Accounts of the various meetings with notes on the technical features have appeared currently in the ASTM BULLETIN.

President Harvey has been much interested in district activities and has attended many of the meetings. An effort has been made in all cases to have a member of the Headquarters staff present also.

This year it was possible for the President and Secretary-Treasurer to make a somewhat overdue visit to the members in the Northern and Southern

California districts. A week each was spent with the Northern district centered in San Francisco and the Southern district centered in Los Angeles; district meetings were held, as noted elsewhere, also valuable conferences with the two district committees, with members of the Society, and with some of the newer and rapidly growing industries on the Pacific Coast, including especially the important aircraft industry. The Secretary-Treasurer also spent several days in New Orleans visiting with a number of our members in that city.

During the year the New York District Committee participated in the work of the Engineering Societies Committee on War Production; the chairman of the district committee, Myron Park Davis, was especially active in arranging for speakers at the War Production Clinic held in that city in January. The Chicago District Committee formally became affiliated with the Chicago Technical Societies Council, with J. F. Calef and E. R. Young officially representing the Society.

The Executive Committee is pleased to note the marked increase in activities of the various district committees. It is anticipated that district groups will continue to occupy a most important place in A.S.T.M. work.

Several of the district committees, through the individuals they have designated as membership chairmen, have cooperated in stimulating interest in new members in their respective districts.

National Meetings:

In the accompanying table are listed all meetings of a national or district nature held during the past year including the 1943 Annual Meeting. Notes on some of the outstanding district meetings have been given in the preceding section of this report. The Annual Meeting in Pittsburgh in June and the Spring Meeting in Cincinnati in March are considered outstanding events and some notes on these are desirable for this record.

Annual Meeting in Pittsburgh, June 28–July 1, 1943.—The Society's Forty-sixth Annual Meeting was held in Pittsburgh under very stringent war conditions, but despite problems of railroad travel and the fact that a large number of our members were under great pressure due to the stress of war production problems, the meeting was outstanding. The third highest registration (1376) in the Society's history was recorded; there were more technical committees convening (245) than during any other annual meeting week, and the technical sessions were of a high caliber. Our annual meetings are always marked for their concentration on business and technical matters, and the Pittsburgh meeting was particularly so, because, due to war conditions, no formal entertainment or social functions were held. The success of the annual meeting is an indication of the importance with which the technical representatives of industry and Government view the Society's work in materials.

Spring Meeting; Committee Week.—The 1944 Spring Meeting in Cincinnati on Thursday, March 2, was featured by a Symposium on Applications of Synthetic Rubbers sponsored by A.S.T.M. Committee D-11 on Rubber Products. This notable technical symposium, very timely because of the great importance of disseminating authoritative information on the use of synthetic rubbers, included 13 technical papers by outstanding authorities. These papers and the discussion have been issued as a separate publication.

The Spring Meeting was held as is customary during A.S.T.M. Committee Week. During this week the Society's technical committees hold their meetings usually over a four- or five-day period and it is pertinent to note that in Cincinnati the meetings were over a six-day period extending from Monday, February 28, through Saturday, March 4.

Another feature of this meeting was the joining of the A.S.T.M. members with the Cincinnati Technical and Scientific Societies' Council in their annual meeting featuring an address by J. L. Collyer, President, The B. F. Goodrich Co. on "America's Rubber Outlook."

Publications:

The publication activities of the Society continued on a very high level despite the fact that the year was one of those intermediate between the appearances of the Book of A.S.T.M. Standards. This was due partly to publication of new editions of a number of compilations of standards (to which a new one was added, namely, that on Paper sponsored by Committee D-6) as well as the issuance of several special publications, including the two Symposiums on Paint and Powder Metallurgy presented at the 1943 Spring Meeting. Two important symposiums have since been held, namely, the Symposium on the Applications of Synthetic Rubbers at the 1944 Spring Meeting, the publication of which was immediately taken in hand, and the very extensive Symposium on Plastics, sponsored by the Philadelphia District Committee in February, 1944, publication of which is planned in the near future.

The special compilations of standards published in the past year are listed below:

A.S.T.M. Specifications for Steel Piping Materials (Committee A-1), 45 standards, 261 pages, 1800 copies, published annually.

Manual of A.S.T.M. Standards on Refractory Materials (Committee C-8), 29 standards, 208 pages, 4000 copies.

A.S.T.M. Standards on Petroleum Products and Lubricants (Committee D-2), 91 standards, 452 pages, 5500 copies, published annually.

A.S.T.M. Standards on Paper and Paper Products (Committee D-6), 37 standards, 144 pages, 1500 copies.

A.S.T.M. Standards on Electrical Insulating Materials (Committee D-9), 74 standards, 514 pages, 1200 copies, published annually.

A.S.T.M. Standards on Rubber Products (with Related Information) (Committee D-11), 65 standards, 434 pages, 1500 copies, published annually.

A.S.T.M. Standards on Textile Materials (with Related Information) (Committee D-13), 79 standards, 468 pages, 1200 copies, published annually.

A.S.T.M. Standards on Plastics (Committee D-20), 85 standards, 438 pages, 5000 copies.

Selected Standards for Students in Engineering, 264 pages, 8000 copies.

The following regular publications were issued and distributed to the members:

1943 *Proceedings*, 1357 pages, 5500 copies, published annually. In addition, preprints of reports and papers totaled 1074 pages, 1700 copies.

1943 Supplements to Book of A.S.T.M. Standards:

Part I, 377 pages, 8700 copies.
Part II, 185 pages, 6750 copies.
Part III, 561 pages, 6500 copies.

A.S.T.M. Methods of Chemical Analysis of Metals, 330 pages, 5000 copies.

Index to Standards, 218 pages, 18,000 copies.

Year Book, 364 pages, 4300 copies.

ASTM BULLETIN, six issues, August, 1943 to May, 1944, 444 pages, average edition, 7400 copies.

A statement of the volume of the principal publications for the past four years follows:

Publications	1940, pages	1941, pages	1942, pages	1943, pages
Proceedings	1403	1388	1225	1356
Book of A.S.T.M. Standards	....	....	4906	....
Supplements to Book of A.S.T.M. Standards	1445	1731	....	1095
A.S.T.M. Methods of Chemical Analysis of Metals	....	....	....	331
Index to A.S.T.M. Standards and Tentative Standards	172	196	206	218
Year Book	320	336	352	364
Spring Meeting Symposiums	100	202	....	135
	3440	3853	6689	3500

The following special publications were also issued:

Symposium on Paint, 74 pages, 2000 copies.

Symposium on Powder Metallurgy, 61 pages, 2500 copies.

Symposium on Mildew Resistance, 36 pages, 1200 copies.

Symposium on the Significance of the Hardness Test of Metals in Relation to Design (a reprint from *Proceedings*) 59 pages, 2000 copies.

Symposium on the Identification of Water-Formed Deposits, Scales, and Corrosion Products by Physico-Chemical Methods (a reprint from *Proceedings*), 39 pages, 2000 copies.

Bibliography and Abstracts on Electrical Contacts (Committee B-4), 143 pages, 1200 copies.

Looking ahead into 1944 publications, the Executive Committee has made an important decision which has already been announced to the membership through the medium of the ASTM BULLETIN, namely, that the revised edition of the Book of A.S.T.M. Standards will be published in 1944 instead of 1945, thus eliminating the 1944 Supplements. This important step has been made necessary by the rapid depletion of the stock of the 1942 Book of Standards. Whereas the number of copies of that book printed were expected to last into the fall of 1945 (the usual triennial period), rapid membership growth and more especially the increasing level of sales have been such that the supply of all three parts of the book will be completely exhausted by the end of this year. The standing committees were immediately advised of this decision, which was taken last January, in order that they might review and bring up to date all standards and tentative standards, especially reviewing the emergency alternate provisions and emergency standards as mentioned earlier in the report.

At the request of the Executive Committee, Committee E-6 on Papers and Publications is examining carefully into the advantages and disadvantages of a proposal that the technical papers and discussions be published in monthly issues of "Proceedings" instead of an annual volume of *Proceedings*. Progress so far made in this study has emphasized its relationship to other publications of the Society, especially the ASTM BULLETIN which in recent years has been used as a means of publishing certain technical papers. Study is also being made of the methods of publishing committee reports and standards of the Society.

Membership:

The membership of the Society on June 1, 1944, was 5257, which is the highest in its history. Statistics showing gains and losses in various classes of membership are shown in the following table:

Class of Membership	Membership		Losses				Additions		Total		
	June 1, 1943	June 1, 1944	Resignations	Dropped	Death	Transfer	Transfer	Election	Loss	Gain	Increase
Honorary	7	10	...	...	..	..	3	...	...	3	3
Perpetuity	9	9	...	...	..	..	..	...	...	...	...
Sustaining	165	188	1	...	..	..	22	2	1	24	23
Company, Firm, etc.	1162	1311	22	9	..	23	9	194	54	203	149
Individual, etc.	3444	3602	82	79	31	12	19	343	204	362	158
Junior	117	137	4	4	1	18	..	47	27	47	20
Total	4904	5257	109	92	32	53	53	586	286	639	353
Student	413	377	18	285	..	13	..	280	316	280	36[a]

[a] Loss.

The net gain for the year of 353 compares with 264 for the preceding year. Elections to membership were close to the highest in the history of the Society and numbered 586, exceeding those for the previous year by 96; losses from resignations and deliquencies were 201 compared to 196 for the preceding year. Junior Members numbered 137 and Student Members 377.

There has been a net increase of 23 in the number of sustaining members, bringing the total to 188. There were 24 new sustaining members and one loss. Of the 24, 22 were acquired by transfer of existing company memberships and two are companies which had not previously held membership in the Society. The names of the new sustaining members are as follows:

American Bosch Corp.
Barber-Green Co.
Bridgeport Brass Co.
Casein Company of America, Division of The Borden Co.
Celanese Corporation of America, Plastics Division
Central Scientific Co.
Cessna Aircraft Co.
Consolidated Mining and Smelting Co. of Canada, Ltd., The
Continental-Diamond Fibre Co.
Fulton Sylphon Co., The
Greiner Co., The Emil
Humble Oil and Refining Co., Petroleum Engineering Dept.
Industrial Synthetics Corp.
International Business Machines Corp.
Kennecott Wire and Cable Co.
Merry Brothers Brick and Tile Co.
National Electric Products Corp.
National Vulcanized Fibre Co.
Permanente Cement Co.
Pittsburgh Plate Glass Co.
Precision Castings Co., Inc.
Precision Scientific Co.
Sharples Chemicals, Inc.
Sheffield Steel Corp.

The Executive Committee expresses on behalf of the Society its thanks to these companies for their willingness to lend financial support to the Society's activities through this form of membership.

The Executive Committee also expresses its thanks to the district committees and the many members of the Society who throughout the year have aided so effectively in the acquiring of new members.

The Executive Committee has elected to honorary membership in the Society the following three members: M. E. McDonnell, Chief Chemist (retired), The Pennsylvania Railroad Co.; Rudolph P. Miller, Consulting Engineer; and Hermann von Schrenk, Consulting Timber Engineer and Past-President of the Society. They will be presented to the Society for formal award of honorary membership during this annual meeting.

In 1938 the Executive Committee established the plan of awarding at the annual meetings certificates commemorating forty years of continuous membership in the Society. Fifty-six such certificates have thus far been awarded and this year thirteen such awards will be made to the following members:

W. F. Angus
Robert A. Cummings
Dominion Bridge Co., Ltd.:
  A. S. Wall
William R. Dunn
Froehling & Robertson, Inc.:
  Grant J. Durant
Illinois Central Railroad Co.:
  C. R. McEwen
C. S. Reeve
Alfred E. Roberts
Herbert L. Sherman
Frank N. Speller
Sanford E. Thompson
Tufts College Engineering School:
  F. N. Weaver
Westinghouse Electric and Manufacturing Co:
  Dean Harvey

The Society has lost the following members through death:

	Date of Membership
Andrews, Frank M.	1923
Baker, Edwin M.	1937
Dunham, L. H.	1938
Geiser, William B.	1923
Hatfield, William Herbert	1927
Hawley, John B.	1928
Heitzman, James L.	1932
Herschel, Winslow H.	1915
Jovanovits, J. A.	1935
Judd, Frank R.	1935
Lee, William	1933
Linch, Harry A.	1937
Main, Charles T.	1921
McNaugher, D. W.	1904
Miller, William J.	1927
Moisseif, Leon S.	1903
Nickerson, J. F.	1912
Nicoll, James S.	1919
Owen Arthur E.	1939
Perdew, W. E.	1920
Perkins, William C.	1923
Rapp, Paul	1937
Ripper, Kurt E.	1939
Schlueter, W. E.	1940
Smith, Emory E.	1906
Squier, George C.	1936
Stadler, John George	1934
Teeple, Charles Paul	1943
Touceda, Enrique	1903
Van Ornum, J. L.	1902
Veitch, F. P.	1908
Weaver, H. A.	1936

The list of deceased members includes many who had contributed in important ways to the advancement of Society affairs. Among them should be mentioned Winslow H. Herschel, D. W. McNaugher, Leon S. Moisseif, William C. Perkins, Paul Rapp, Enrique Touceda, and F. P. Veitch.

Finances:

Report for the Fiscal Year 1943.—The annual statement of the finances of the Society follows in the report of the auditors for the fiscal year, January 1 to December 31, 1943. The report gives the balance sheet of assets and liabilities, including special and designated funds (that is, the Research Fund, Medal and Lecture Fund, and Committee Funds); statement of receipts and disbursements, which items are classified into "operating" (budgeted) and "nonoperating"; details of special funds; and investment of Society funds, both book and market values being given.

Total receipts from dues and entrance fees in 1943 were $111,255.95, an increase of nearly $10,000 over the preceding year. Receipts from sales of publications totaled $132,169.00—larger by far than in any previous year. Several items contributed especially to this total: the large sale of the 1942 Book of Standards, Supplements, and Chemical Analysis of Metals, grossing approximately $67,980; the sales of compilations of standards, standards for students, and of separates, approximately $34,220—bringing the total sales of standards in all forms to about $102,200; and the sales of special publications (exclusive of compilations of standards) amounting to about $18,800. Miscellaneous receipts amounted to $19,213.88, consisting principally of receipts from advertising in the ASTM BULLETIN and Index to Standards, receipts from interest and dividends, and registration fees.

Total operating receipts were $262,638.83. Operating disbursements with all current bills paid (as detailed in the auditors' report) were $216,899.91, to which should be added the sum of $15,000 set aside from current funds for the reserve for the next Book of Standards, which brings the total operating disbursements to $231,899.91. Increased volume of publications, increased printing costs and enlargement of the Society staff, as well as the rising scale of prices generally, all contributed to this largest disbursements total in the Society's history; but notwithstanding, there resulted a favorable balance between operating receipts and disbursements of $30,738.92, which will be used to cushion possible operating deficits in the future and to provide for suitable expansion of the Society's work.

Attention is called to the fact that the disbursements include $2300 (approximately one half the entrance fees) paid into the principal of the Research Fund and $4175.95 paid towards the Employees' Retirement Plan. The latter amount includes $2524.04 covering the premiums for five years on three retirement policies taken out in May, 1943 as part of the Plan. There is also included nearly $3000 spent on emergency alternate provisions and emergency specifications, which together with similar expenditures for 1942 of about $5900 totals about $8900 for this direct contribution to the war effort, for it has been the exigencies of war emergency that necessitated this work.

The auditors' report includes a statement of the financial condition of the Society for the past five years. The surplus in the general funds account, exclusive of special and designated funds, is $105,660.86, compared to $84,577.11 a year ago. This substantial increase is, of course, gratifying; but the true significance of surplus can only be seen in its relation to the level of operations of the Society, which can be expressed by the percentage ratio of surplus to operating disbursements. When these ratios are determined for the past five years, it is seen that although the dollar value of surplus has nearly doubled in five years, the ratio of surplus to operations of the Society has increased only from 38 to 46 per cent.

Attention is called to the amounts reported in the various funds under the statement of liabilities. There were no significant changes during 1943 in the Life Membership Fund, Headquarters Fund, or Publication Fund. The Book of Standards Reserve at $17,113.98 is made up of $2113.98 carried over from the previous reserve and $15,000 added from current income. The Executive Retirement Reserve at $6345 includes $3000 added from current income. Another $3000 was added to the Retirement Fund Reserve, bringing it to a total of $3288.95. During the year a Reserve Against Depreciation of Investments of $10,000 was established.

Investments of Society funds as of December 31, 1943, are given in the auditors' report, both book and market values being shown. The following changes during the fiscal year in the investment portfolio are noted:

GENERAL FUNDS

Bought		*Cost*
$4000	U. S. Treasury Bonds 1964–69	$4000.00
6000	U. S. Defense Savings Bonds, Series G	6000.00
8000	U. S. Certificates of Indebtedness	8015.31
3	shares American Cyanamid Co. 5% Cumulative Pfd. (dividend)	...
67	shares Philadelphia Electric	1185.06
16	shares Public Service Corp. of N. J.	240.00
100	shares Philco Corp.	2380.91
50	shares Sperry Corp.	1510.00
50	shares Texas Co.	2519.55
52	shares Westinghouse Electric & Manufacturing Co.	4914.26
Sold		*Received*
$4000	New York, Chicago & St. Louis R. R. Bonds (Gain $381.79)	$3187.40
3000	Alvin Progressive Federal Savings & Loan Assn.	3000.00
3000	Collingdale Progressive Federal Savings & Loan Assn.	3000.00
50	shares General Electric Co. (Loss ($172.41)	1833.84

RESEARCH FUND

Bought		*Cost*
$1500	U. S. Defense Savings Bonds Series G	$1500.00
33	shares Philadelphia Electric Co.	583.70
9	shares Public Service Corp. of N. J.	135.00
50	shares Sperry Corp.	1510.00
Sold		*Received*
$2000	New York, Chicago & St. Louis R. R. Bonds (Gain $193.43)	$1593.69

No account has been taken in the accompanying financial statement of the assets of the Society in the form of publications in stock. An inventory of technical publications as of June 1, 1944, may be summarized as follows:

		Number of Copies
Year Book		600
Proceedings		4 280
Index to Proceedings, 6 parts, total		1 602
1942 Book of A.S.T.M. Standards:		
Part I	599	
Part II	500	
Part III	541	
	—	
1943 Supplements to the Book of Standards:		
Part I	1440	
Part II	981	
Part III	744	
	—	
		3 165
Methods of Chemical Analysis of Metals		1 847
Index to A.S.T.M. Standards		1 584
Selected Standards for Students in Engineering		4 110
Reprints of Standards (approximate)		90 000
Special Reprints (approximate)		50 000

REPORT OF THE AUDITORS FOR THE FISCAL YEAR, JANUARY 1, TO DECEMBER 1, 1943

Philadelphia, January 7, 1944.

MR. C. L. WARWICK, *Secretary-Treasurer*
AMERICAN SOCIETY FOR TESTING MATERIALS
Philadelphia, Pennsylvania

Dear Sir:

We have examined the books and accounts of your Society for the period from January 1, 1943 to December 31, 1943. We did not make a detailed audit of all transactions, but made extensive tests to determine the accuracy of your records; nor did we verify accounts receivable by correspondence with debtors.

We have prepared and submit herewith balance sheet as of December 31, 1943, statement of cash receipts and disbursements for the year ended that date, and other supporting schedules, all of which are in agreement with the records of your Society. In our opinion, these statements present fairly the financial position of the Society at December 31, 1943, and the results of its operations for the year then ended.

The investments owned by the Society as detailed herein were examined by us. All income from investments was properly accounted for.

Respectfully submitted,
JOHN HEINS & CO.
(Signed) WILLIAM M. GWYNN
Certified Public Accountant

BALANCE SHEET AS OF DECEMBER 31, 1943

(Including Special and Designated Funds)

ASSETS

General Funds:			
Current: Cash	$62 220.41		
Less checks drawn as of December 31, 1943—cost of 1943 *Proceedings* ($13 800.00), 1943 Supplements to Book of Standards ($17 500.00) and Emergency Alternate Provisions ($1 700.00) in hands of Secretary-Treasurer that date	33 000.00		
		$29 220.41	
Investments (Market Value, $103 740.07)—Cost		111 136.68	
Accounts Receivable		14 567.65	
Total Current Assets—General Fund			$154 924.74
Furniture and Fixtures (depreciated book value)			6 960.38
Total Assets General Funds			$161 885.12
Special and Designated Funds:			
Cash: A.S.T.M. Research Fund		$3 170.78	
Dudley Medal and Marburg Lecture Fund		519.18	
Committee Funds		10 484.75	14 174.71
Investments:			
A.S.T.M. Research Fund (Market Value, $31 040.76)—Cost or book value		$33 757.93	
Dudley Medal and Marburg Lecture Fund (Market Value, $2 755.00)—Cost		6 625.00	
Committee Funds (Market Value, $6 292.50)—Cost		6 000.00	
			46 382.93
Total Assets Special and Designated Funds			$60 557.64
Total Assets			$222 442.76

LIABILITIES

General Funds:			
Current: Accounts Payable:			
Committee C-1	$174.85		
Advance Collections	5 394.17		
Total Current Liabilities—General Fund		$5 569.02	
Life Membership Fund	3 005.20		
Headquarters Fund	5 887.11		
Publication Fund	5 015.00		
Book of Standards Reserve	17 113.98		
Executive Retirement Reserve	6 345.00		
Retirement Fund Reserve	3 288.95		
Reserve against Depreciation of Investments for Special and Designated Fund	10 000.00		
Surplus	105 660.86		
		156 316.10	
Total Liabilities General Funds			$161 885.12
Special and Designated Funds:			
A.S.T.M. Research Fund:			
Principal	35 496.82		
Income	1 431.89	$36 928.71	
Dudley Medal and Marburg Lecture Fund:			
Principal	6 625.00		
Income	519.18	7 144.18	
Committee Funds		16 484.75	
Total Special and Designated Funds			60 557.64
Total Liabilities and Funds			$222 442.76

COMPARISON OF GENERAL FUNDS FOR FISCAL YEARS 1939–1943, INCLUSIVE

At close of Fiscal Year	Assets				Liabilities			
	Cash	Investments	Accounts Receivable	Furniture and Fixtures	Accounts Payable	Reserve for Book of Standards	Miscellaneous Funds	Surplus
1939	$9 329.65	$54 902.10	$14 880.53	$6 467.27	$5 777.01	$12 000.00	$9 685.40	$58 117.14
1940	9 608.61	72 568.95	13 388.88	6 561.93	3 380.25	7 890.25	9 713.79	81 144.08
1941	18 206.61	88 001.45	14 120.99	6 440.58	3 937.44	13 890.25	12 907.43	96 034.51
1942	14 915.67	93 281.45	6 846.09	6 362.86	5 036.28	13 890.25	17 902.43	84 577.11
1943	29 220.41	111 136.68	14 567.65	6 960.38	5 569.02	17 113.89	33 541.26	105 660.86

RECEIPTS AND DISBURSEMENTS

FOR THE PERIOD ENDED DECEMBER 31, 1943

Cash balance, January 1, 1943			$14 915.67

RECEIPTS

Operating Receipts (Budgeted):			
Dues and Entrance Fees:			
Current Dues	$102 819.58		
Past Dues	863.30		
Advance Dues	2 768.23		
Income, Life Membership Fund	150.00		
Entrance Fees	4 654.84		
Total Dues		$111 255.95	
Sale of Publications:			
Separate Standards	$8 561.76		
Book of Standards (Members, additional parts)	7 015.50		
1939 Book of Standards & Supplements	1 560.88		
1942 Book of Standards	62 204.14		
1943 Supplements to Book of Standards	764.08		
Methods of Chemical Analysis of Metals	3 454.48		
Proceedings	3 534.44		
Collective Index to Papers and Reports	112.32		
Selected Standards for Students	2 654.81		
Bulletin Subscriptions (Nonmembers)	505.55		
Special Reprints and Miscellaneous	41 801.04		
Total Sale of Publications		$132 169.00	
Miscellaneous:			
Binding (Members)	193.00		
Advertising, Bulletin	10 246.19		
Advertising, Index	1 852.03		
Interest and Dividends	4 470.16		
Registration and other fees, Annual Meeting	1 474.00		
Committee A-1 Technical Assistant	788.00		
Miscellaneous	190.50		
Total Miscellaneous Items		$19 213.88	
Total Operating Receipts (Budgeted)		$262 638.83	
Nonoperating Receipts (Not Budgeted):			
Investments, Matured or Sold	$11 021.24		
Excess Remittances	873.30		
Committee C-1 for Technical Assistant	1 600.00		
Executive Retirement Reserve	225.00		
Retirement Fund Reserve	203.20		
Total Nonoperating Receipts		$13 922.74	
Total Receipts			$276 561.57
Total Receipts and Cash Balance, January 1, 1943			$291 477.24

Brought Forward			$291 477.24

DISBURSEMENTS

Operating Disbursements (Budgeted):			
Publications:			
Year Book	$3 653.26		
1943 Supplements to Book of Standards	18 914.87[a]		
Emergency Alternate Provisions	2 977.82[a]		
Methods of Chemical Analysis of Metals	3 634.60		
Selected Standards for Students	1 474.00		
Proceedings	16 092.19[b]		
Collective Index to Papers and Reports	310.40		
Preprints	3 047.81		
Spring Meeting Papers	856.00		
ASTM Bulletin	9 734.55		
Circulars to Members	1 446.84		
Separate Standards	4 314.53		
Index to Standards and Tentative Standards	3 765.13		
Reprints (Reports, Papers, Symposiums, etc.)	22 505.47		
Miscellaneous Printing (Authors' Reprints, etc.)	363.19		
Total Disbursements, Publications		$93 090.66	
Salaries		78 200.14	
General Office Expenses		16 122.42	
Expenses, Standing and District Committees		3 689.78	
Expenses, Meetings		4 249.63	
Traveling Expenses, Administrative and Special Committees		3 573.75	
American Standards Assn. and Sectional Committees		1 000.00	
Rent, Headquarters		8 610.48	
Furniture and Fixtures		1 042.49	
Principal, A.S.T.M. Research Fund		2 300.00	
Employees' Retirement Fund		4 175.95	
War Emergency Expense		239.55	
Miscellaneous, Dues, Contributions		605.06	
Total Operating Disbursements (Budgeted)		$216 899.91	
Nonoperating Disbursements (Not Budgeted):			
Investments	$29 340.03		
Refund of Excess Remittances	871.10		
Headquarters Fund	789.37		
Purchase of Retirement Income	980.15		
Book of Standards (Reserve)	11 776.27		
Technical Assistant Committee C-1	1 600.00		
Total Nonoperating Disbursements		$45 356.92	
Total Disbursements			$262 256.83
Cash Balance, December 31, 1943			$29 220.41

---

[a] This amount includes $17 500.00 covering checks drawn against cost of the 1943 Supplements to the 1942 Book of A.S.T.M. Standards and $1 700.00 for Emergency Alternate Provisions, but not actually paid on December 31, 1943.

[b] This amount includes $13 800.00 covering checks drawn against cost of *Proceedings*, but not actually paid on December 31, 1943.

In addition to the general funds of the Society, the Secretary-Treasurer has on hand the following funds:

A.S.T.M. RESEARCH FUND

	Total	Invested	Uninvested Cash
Principal Account:			
Balance January 1, 1943	$33 548.69	$32 693.49	$855.20
Receipts:			
Contribution—A.S.T.M. on account of Current Entrance Fees	+2 300.00		+2 300.00
Sale of Securities	+193.43	−1 400.26	+1 593.69
	$36 042.12	$31 293.23	$ 4 748.89
Disbursements: Purchase of Securities		+3 010.00	−3 010.00
	$36 042.12	$34 303.23	$1 738.89
Write down of U. G. I. common stock to market value of June 16, 1943	545.30	545.30	
Balance, December 31, 1943	$35 496.82	$33 757.93	$1 738.89
Income Account:			
Balance, January 1, 1943	$787.12		
Receipts:			
Interest and Dividends on Investments	1 144.77		$1 931.89
Disbursements:			
Research Committee on Fatigue of Metals			500.00
Cash Balance, December 31, 1943			$1 431.89

DUDLEY MEDAL AND MARBURG LECTURE FUND

Balance, January 1, 1943:			
Principal—Investments (at cost)	$6 625.00		
Income—Cash	694.93	$7 319.93	
Receipts			
Interest on Investments		66.00	$7 385.93
Disbursements			
Engrossing 1943 Lecture Certificates		$3.25	
Honorarium, 1943 Lecturer		200.00	
Cost of 1943 Medal		38.50	241.75
			$7 144.18
Balance, December 31, 1943:			
Principal—Investments (at cost)		$6 625.00	
Income—Cash		519.18	$7 144.18

COMMITTEE FUNDS

Committee A-1 on Steel		$876.59	
Committee A-5 on Corrosion of Iron and Steel		3 101.28	
Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys		2 951.02	
Committee B-6 on Die-Cast Metals and Alloys		2 869.00	
Committee C-1 on Cement		743.13	
Committee C-1—Cement Reference Laboratory		600.32	
Committee C-9 on Concrete and Concrete Aggregates		197.12	
Committee C-9 Sanford E. Thompson Medal Fund		440.25	
Committee C-15 on Manufactured Masonry Units		351.86	
Committee C-18 on Natural Building Stones and Slate		173.36	
Committee D-1 on Paint, Varnish, Lacquer, and Related Products		82.50	
Committee D-2 on Petroleum Products and Lubricants		123.37	
Committee D-5 on Coal and Coke		1 293.50	
Committee D-12 on Soaps and Other Detergents		69.00	
Committee D-13 on Textile Materials		697.29	
Committee D-13—Testing Textile Finishes		265.38	
A.S.A. Sectional Committee on Specifications for Cast-Iron Pipe and Special Castings		106.17	
Research Committee on Fatigue of Metals		359.21	
Detroit District Committee		1 184.40	
Total Committee Funds			$16 484.75
Accounted for as follows:			
Cash Balance, December 31, 1943		$10 484.75	
Investments—at cost		6 000.00	
			$16 484.75

INVESTMENTS
AS OF DECEMBER 31, 1943
GENERAL FUNDS

Number of Shares or Par Value		*Cost or Book Value*	*Market Value*
	Bonds		
$3 000	Armour & Co. of Del., First Mortgage, 20-yr., Sinking Fund, Series C, 4's due 1957	$2 955.00	$3 172.50
9 000	Balto. & Ohio R.R., Refunding and General Mortgage 5's, Series F, 1996	9 106.55	3 780.00
2 000	Columbia Gas & Electric Co., Debentures, 5's due 1961	2 025.34	2 072.50
500	Florida Power & Light Co., First Mortgage, 5's, due 1954	491.25	509.38
4 000	General Steel Castings Corp., First Mortgage, Series A, 5½'s, due 1949	3 610.00	4 060.00
3 000	Michigan Consolidated Gas Co., First Mortgage, 4's, due 1963	2 925.00	3 127.50
3 000	Press Steel Car Co., Inc., 15-yr. Debentures, 5's, due 1951	2 868.75	3 075.00
13 000	U. S. Defense Savings Bonds, Series G[c]	13 000.00	12 597.00
3 800	U. S. Treasury Bonds, 2½'s, due 1967–72	3 800.00	3 813.06
4 000	U. S. Treasury Bonds, 2½'s, due 1964–69	4 000.00	4 000.00
8 000	U. S. Certificates of Indebtedness, December, 1944	8 015.31	8 008.00
		$52 797.20	$48 214.94
	Stock		
25	American Can Co., common	2 122.30	2 087.50
19	American Cyanamid Co., 5 per cent Cumulative preference	190.00	218.50
50	American Cyanamid Co., Class B common	1 764.25	2 000.00
100	American Radiator & Std. Sanitary Corp., common	1 564.32	912.50
25	American Tobacco Co., common	2 110.12	1 425.00
100	Atlantic Refining Co., common, par value $25	2 302.50	2 550.00
100	Borden Co	1 989.00	2 900.00
25	Colgate-Palmolive-Peet Co., $4.25 preferred	2 525.00	2 631.25
50	General Telephone Corp., $2.50 preferred	2 675.00	2 593.75
50	Great Northern Ry., $6 preferred par value $100.	1 774.83	1 300.00
25	Hazel Atlas Glass Co	2 510.64	2 656.25
100	S. S. Kresge Co., common	2 490.18	2 300.00
100	Mathieson Alkali Works, common, no par value	3 016.00	2 100.00
20	G. C. Murphy Co., 4¾ per cent preferred	2 100.00	2 300.00
25	J. C. Penney Co., common	2 279.63	2 431.25
67	Philadelphia Electric Co., common	1 185.06	1 465.63
100	Philco Corp., common	2 380.91	2 550.00
116	Public Service Corp. of N. J., common	4 369.50	1 566.00
25	Sears, Roebuck & Co., Capital	1 760.71	2 225.00
50	Sperry Corp., common	1 510.00	1 312.50
50	The Texas Company	2 519.55	2 400.00
200	United Gas Improvement Co., common	450.00	525.00
50	U. S Gypsum, common	3 819.27	3 650.00
100	Westinghouse Elec. & Mfg. Co., common	8 930.71	9 425.00
		$58 339.48	$55 525.13
		$111 136.68	$103 740.07

A.S.T.M. RESEARCH FUND

Number of Shares or Par Value		*Cost or Book Value*	*Market Value*
	Bonds		
$2 000	First Mortgage Real Estate, 1315–1317 Spruce St., 6's, due 1945[a]	$2 000.00	$600.00
1 000	Allis Chalmers Mfg. Co., Convertible Debentures, 4's, due 1952	1 035.28	1 077.50
1 500	Balto. & Ohio R. R. General & Refunding, 5's, Series F, due 1996	1 511.25	630.00
2 000	Columbia Gas & Electric Co., Debentures, 5's, due 1961	2 025.31	2 072.50
1 500	Florida Power & Light Co., First Mortgage, 5's, due 1954	1 473.75	1 528.13
3 000	Republic Steel Corp., General Mortgage, Series B, 4½'s, due 1961	3 000.00	3 157.50
4 500	U. S. Defense Savings Bonds, series G[b]	4 500.00	4 389.00
		$16 945.85	$13 454.63
	Stock		
12	Consolidated Edison Co. of N. Y. $5 preferred	1 234.39	1 245.00
29	Consumers Power Co. $4.50 preferred, no par value	2 914.50	2 965.25
98	General Motors Corp., common, par value $10[c]	6 504.75	5 145.00
30	G. C. Murphy Co. 4¾ per cent preferred	3 150.00	3 450.00
33	Philadelphia Electric Co., common	583.70	721.88
25	Pittsburgh Plate Glass Co., common	1 955.00	2 362.50
9	Public Service Corp. of N. J., common	135.00	121.50
50	Sperry Corp., common	1 510.00	1 312.50
100	United Gas Improvement Co., common	225.00	262.50
		$16 812.08	$17 586.13
		$33 757.93	$31 040.76
	DUDLEY MEDAL & MARBURG LECTURE FUND		
$ 500	Balto. & Ohio R. R. Refunding & General Mortgage, 6's, Series C, due 1995	550.00	235.00
6 000	Balto. & Ohio R. R. Refunding & General Mortgage, 5's, Series A, due 1995	6 075.00	2 520.00
		$6 625.00	$2 755.00
	COMMITTEE FUNDS		
$5 000	U. S. Treasury Bonds, 2¾'s, 1947–45	5 000.00	5 176.56
1 000	U. S. Treasury Bonds, 2⅞'s, 1960–55	1 000.00	1 115.94
		$6 000.00	$6 292.50
	Grand Total	$157 519.61	$143 828.33

---

[a] Market values were taken from current financial publications with the exception of quotations on inactive or unlisted securities indicated by footnote [a]. These values were obtained from brokers as of December 31, 1943.

[b] Market value is stated at redemption values as of December 31, 1943.

[c] The income from these shares is, by agreement, paid to an annuitant.

1944 Finances.—The Society's operations for 1944 are based upon estimated current operating receipts of $237,500, to which has been added from surplus for current operations the sum of $7000, bringing the total of budgeted receipts to $244,500. Receipts from dues and entrance fees are estimated at $113,500; receipts from sales of publications at $106,500; miscellaneous receipts, including advertising, interest and dividends are estimated at $17,500. Disbursements have been estimated at $244,500. This amount provides fully for the normal operating expenses of the Society and for the increased publications expense due to the republishing of the Book of Standards in 1944, a year ahead of the normal time. Adequate provision is made for all current publications, emergency specifications, activities of standing and district committees, as well as provision for expansion of the Society staff.

The Executive Committee reviews the budget of receipts and disbursements quarterly and makes any adjustments that may be necessary. One adjustment that has been made is to provide for the additional expenses that are being incurred in expanding the Employees Retirement Plan as noted later in the report.

From the surplus at the end of 1943, the Executive Committee has transferred $1000 to the Headquarters Fund, $1000 to the Executive Retirement Reserve, and $2000 to the Reserve Against Depreciation of Investments, bringing the totals of these three funds respectively to $6887.11, $7345, and $12,000.

Since January 1, 1944, securities have been sold yielding $16,008.80 and investments have been made in the sum of $26,159.29, including $12,000 invested in Government bonds. The total book value of Society investments as of May 31, 1944, in all funds was $163,705.82. The market value of these securities on the same date was $160,208.41. The Society's cash balance on May 31, 1944, was $139,014.74.

After reviewing the practices of a number of the other technical societies, the Executive Committee has decided that its members should be reimbursed for their transportation expenses, sustenance during transportation and hotel expenses for one day in connection with the meeting of the Executive Committee held during the Annual Meeting of the Society. A revision of the Regulations Governing the Executive Committee in accordance with this action has been made.

Retirement Plan for Employees:

The Executive Committee has now found it possible to place the Employees Retirement Plan on a basis that more fully recognizes "past service credits" than had heretofore been possible because of financial limitations. Effective on the sixth anniversary of the Plan, May 4, 1944, it was augmented by bringing retirement annuities up to approximately 1 per cent for each year of service at retirement (figured as age 60 for women and 65 for men), based on the average of the five highest salaried years before retirement—except that no portion of any salary over $5000 has been included in determining retirement values. For this purpose, for all employees participating in the Plan on April 30, 1944, who contribute 2½ per cent of their salaries toward their retirement policy or policies (which 2½ per cent is matched by the Society under the terms of the Plan), the Society will provide additional retirement policies in the Penn Mutual Life Insurance Co., the premiums for which will be paid by the Society alone, that is, "unmatched" by the employee. The Society, under all conditions except actual retirement, retains all equity in any "unmatched" policy or "unmatched" portion of any policy. All employees participating must keep their contributions up to 2½ per cent of salary. Sixteen employees participating in the Plan as of April 30, 1944, having agreed to these conditions and brought their own contributions up to 2½ per cent of salary, "unmatched" policies have been acquired for these employees at total annual premiums of approximately $5950. Adding to this the amount of the Society's matching of employees' contributions, including several "partially unmatched" policies, approximately $2010, brings the total annual contribution of the Society to the Retirement Plan to about $7960, which is roughly 9 per cent of the present salary roll and 3 per cent of the estimated current disbursements. The total of employees' annual contributions, including insurance benefits which most of them have elected, is approximately $2145.

Since April 30, 1944, one additional employee has entered the Plan, bringing the total number of participants to 18 of the 20 eligible employees. The remaining seven employees of the Society are not yet eligible for participation, having been with the Society less than one year.

It must be remembered that the Society and its employees are not included in the present Social Security Laws. To provide funds that would be required for an estimated five years at present rates if these Laws are amended to include the Society and its employees, is the principal purpose of the Retirement Fund Reserve now totalling $3288.95. The Executive Retirement Reserve, which now totals $7345 by the addition last January of $1000 from surplus, is intended primarily to meet retirement needs that for various reasons cannot be provided through the policies in the Retirement Plan itself.

Society Headquarters:

The Executive Committee has appointed a special committee of Philadelphia members, consisting of Messrs. E. J. Albert, Chairman, G. H. Clamer, P. H. Dike, Alexander Foster, Jr., and J. F. Vodges, Jr., to study fully all the pros and cons of Society-owned *versus* leased headquarters and to report recommendations to the Executive Committee, with particular reference to the possibility of acquisition of a suitable property in Philadelphia for a Society home.

Cooperative Activities:

The Society's cooperative relations with other organizations have been maintained from the inception of its work and have continued along well-established lines. An illustration this year is the formation of an Inter-Society Council on Textile Research, to coordinate the interests and activities of a number of national organizations in research in the entire textile field. H. J. Ball, Past-President of the Society and chairman of Committee D-13 on Textiles, has been named as the Society's representative on the Council, with A. G. Ashcroft as alternate. Another example is the formation of a Joint Committee on Vapor Barrier Studies with the American Society of Heating and Ventilating Engineers and the American Society of Refrigerating Engineers, in which the interests of A.S.T.M. through Committee C-16 on Thermal Insulating Materials are joined with those of the other societies in an important research project sponsored by the War Production Board at the University of Michigan.

The cooperative work with the Society of Automotive Engineers on natural and synthetic rubbers for automotive and aeronautical uses, which is carried out through a joint committee that functions as Technical Committee A of Committee D-11 on Rubber Products, has been strengthened by a reorganization of the committee personnel, dropping some members who were no longer active and bringing in new members, especially several representatives of the aircraft industry.

The Society has become an associate member of the Engineering College Research Association in order that it might keep more closely in touch with research activities going on in the colleges and universities of the country.

To further its cooperative efforts with the American Foundrymen's Association, the Executive Committee has appointed Sam Tour to represent the Society (through Committee B-7 on Light Metals and Alloys) on the Advisory Committee of the Aluminum and Magnesium Division of that Association.

American Standards Association:

The Society's contacts with the American Standards Association continue to constitute one of its most important cooperative activities. Information on the submission of new and revised standards for approval as American Standard is covered in the annual report of Committee E-10 on Standards.

The Executive Committee has been examining some questions of a fundamental nature regarding the relationships between the Society and the American Standards Association. To this end it has placed certain questions before the Special Study Committee, referred to earlier in this report, for its detailed consideration. The ASA has also appointed special committees of its Board of Directors and its Standards Council for the purpose of reviewing policies and procedures and making recommendations for the future development of ASA. The Society is directly represented on the Council's committee by one of its representatives on the Council, H. H. Morgan. This has afforded an opportunity for presentation of the Society's views, which has been supplemented by conferences between officers of the Society and officers of ASA. Moreover on May 5 the special committee of the Board of Directors held a conference with representatives of some fifteen member bodies of ASA, at which the Society was represented by Vice-President J. R. Townsend and the Secretary-Treasurer, and at which opportunity was afforded for the presentation of the viewpoints and recommendations of the member bodies respecting ASA activities and procedures.

In all of these conferences the views of the Society have been vigorously presented, and the Executive Committee will continue to keep closely in touch with developments, working always to the end that the ASA shall be as planned the central clearing house of American standardization activities in this country but not in itself a standardizing body as such, towards which there seems to have been an undesirable trend, in the opinion of the Executive Committee.

F. M. Farmer has been reappointed for a term of three years as an A.S.T.M. representative on the ASA Standards Council. R. P. Miller was reappointed on the ASA Building Code Correlating Committee.

International Standardization Activities:

There is in course of formation a United Nations Standards Coordinating Committee, membership upon which is open to national standards associations of such of the united nations as may wish to participate in and support the work of the committee. The objectives are to promote the maximum possible coordination and unification of standards necessary for the war effort and the immediate post-war period. The committee is to be established for a two-year period, with the understanding that its organization will be reviewed towards the end of that period. The American Standards Association, which is the accepted channel for American collaboration in international standardization affairs, has accepted membership on the Coordinating Committee and has agreed to contribute $10,000 a year for two years towards the financial support of the work. It is intended that the Coordinating Committee will maintain one senior staff officer in the United States and one in Great Britain, who shall cooperate as a single central office.

The Executive Committee of the Society believes that the formation of the United Nations Standards Coordinating Committee is a desirable move, providing as it will a means of considering important international standardization problems between now and the time that the pre-war international standardization bodies can be reconstituted. The Executive Committee has expressed to the ASA the interest of this Society on all questions concerning materials standards that may come before the UNSCC and has asked that work to be done in this country on materials for international standardization be channeled to the Society as the logical member body of ASA to sponsor such activities. Consideration is now being given in ASA to the development of a procedure governing relations with the UNSCC.

The work in promotion of inter-American standardization through a department of ASA, to which reference was made in the report a year ago, has continued actively during the year with the Society taking a formal part through membership of the Secretary-Treasurer on the ASA Committee on Inter-American Affairs. An extensive report by C. T. Brady, Jr., the Latin-American field representative of the ASA on "Standardization Movement in Latin America" is an informative and useful document in this important movement. Interest of the Latin-American countries in A.S.T.M. standards continues to be active and an increasing number of A.S.T.M. publications are going to the standardizing bodies and engineers of those countries. Representations have been made by the Society to the ASA concerning the importance of the relationship between the United Nations Standards Coordinating Committee above mentioned and the development of inter-American standardization policies and procedures.

Respectfully submitted on behalf of the Executive Committee,

DEAN HARVEY,
President.

C. L. WARWICK,
Secretary-Treasurer.

JUNE, 1944.

REPORT OF COMMITTEE A-1
ON
STEEL

Despite the opinion of Committee A-1 on Steel as expressed at its March, 1942, meeting that changes in standards should be kept to a minimum during the war emergency, a rather large number of revisions are recommended in this report. They are occasioned by the fact that many are of much importance in connection with the sustained high production of steel products and therefore should be made as soon as possible, and also by the advancement by one year of the publication date of the new Book of A.S.T.M. Standards. It is desirable that the some 130 specifications under the jurisdiction of Committee A-1 be as up to date as possible and incorporated in the new Book of Standards in their latest form.

Although some of the proposals involve the withdrawal of a few emergency alternate provisions and the incorporation of some of these requirements in the regular specifications, for the most part they are being continued. Many of the emergency provisions are covered by War Production Board Steel Limitation Order L-211 and its various schedules, and furthermore, the committee feels that with current steel-making practices based on widespread use of the provisions their availability and current standing should not be modified. There is little question but that eventually many of these provisions will be incorporated in the specifications.

Meetings.—Most of the recommendations on specifications incorporated in this report were developed at the extensive series of meetings held in Cincinnati, Ohio, on February 29 and March 1, 1944, during A.S.T.M. Committee Week, the only other series of meetings held by Committee A-1 during the year being those in Pittsburgh, Pa., on June 29 and 30, 1943. To conserve the time of members, the customary series of meetings in January was not held, but during the year a number of meetings of sections and subcommittees have taken place. The attendance at all meetings has been high and there has been no diminution in the interest of the members.

Personnel.—Since the 1943 Annual Meeting, 11 new members have been elected and 3 resignations accepted, the committee membership now totalling 242, of whom 127 are classified as nonproducers and 115 as producers; of the former, 90 are consumers and 37 are general interest members.

Losses by Death.—During the year Committee A-1 has lost by death five members: L. H. Dunham, American Steel and Wire Co.; E. F. Kenney, Bethlehem Steel Co.; Leon Moisseiff, Consulting Engineer; I. L. Pyle, Chesapeake and Ohio Railroad; and J. S. Richards, American Steel and Wire Co. Each of these men had contributed to the work of the committee. Mr. Pyle, as representative of a large consumer of steel and steel products, had participated in the work of several subcommittees; Mr. Moisseiff, a designer of many of the world's largest bridges and steel structures, was concerned with steel specifications and participated in the work of Subcommittee II on Structural Steel.

He had been a member of the Society for almost 40 years and was a member of the committee for many years. With respect to the late Mr. Kenney, special mention should be made of his long-time and active service on Committee A-1 on Steel, and in the following notes on his activities, the Steel Committee pays tribute to his work and records its appreciation of his long-time and active service:

RESOLUTION ON THE DEATH OF E. F. KENNEY

(1869–1943)

In the death on July 8, 1943, of E. F. Kenney, Metallurgical Engineer, Bethlehem Steel Co., Bethlehem, Pa., Committee A-1 loses a member and officer who, for almost four decades had participated actively in its work. Producer Vice-Chairman of the committee since 1926, he was honored at the June, 1943, meeting by election as Honorary Vice-Chairman. He had served as chairman of Subcommittee I on Steel Rails and Accessories since its formation in 1912, and had served in various capacities in connection with the activities of several other subcommittees concerned with structural steel, steel wheels and tires, plates for boilers and pressure vessels, and others.

Following his early experience with the Pennsylvania Railroad, he was Metallurgical Engineer for Cambria Steel Co. which was his position when he became a member of the Society in 1904; later he became affiliated with the Bethlehem organization. Mr. Kenney had been continuously affiliated with Committee A-1 on Steel longer, with one exception, than any other individual, and up until a few weeks before his death, was participating in the work. In this resolution, Committee A-1 on Steel records its profound respect for his longevity of service, its appreciation of his many contributions to the work of the committee, and its keen regret at his passing.

Representation on Other Committees.—P. G. McVetty, will represent Committee A-1 on Technical Committee IX on Designation and Interpretation of Numerical Requirements, of Committee E-1 on Methods of Testing. W. M. Barr, will represent Committee A-1 on Committee E-3 on Chemical Analysis of Metals, and on Subcommittee VII on Chemical Composition, of Committee E-1. M. E. McDonnell, who has retired, is relinquishing his committee work.

EMERGENCY ALTERNATE PROVISIONS

Since the 1943 Annual Meeting, several emergency alternate provisions have been accepted by Committee E-10 on Standards on the recommendation of Committee A-1, some of which were referred to in the editorial note appended to the 1943 Report. Three, approved on August 30, 1943, involve the Standard Specifications for Electric-Resistance-Welded Steel Heat-Exchanger and Condenser Tubes (EA - A 214a), Carbon-Steel Plates for Stationary Boilers and Other Pressure Vessels (EA - A 70), and Low Tensile Strength Carbon-Steel Plates of Flange and Firebox Qualities (EA - A 89). Six other emergency alternate provisions affecting certain plates used in boiler and other pressure vessel construction, providing for limited marking of small plates, are being withdrawn and the requirements incorporated in the specifications as detailed in the Appendix.

Steel Castings.—On April 26, 1944, emergency alternate provisions became effective involving three widely used specifications for steel castings for high-temperature service, A 95 (carbon steel), A 157 (alloy steel), and A 216 (carbon steel for welding). One part of the emergency alternates provides emergency hydrostatic test pressure requirements which tie in with the American War Standard for Pressure-Temperature Ratings for Steel Pipe Flanges, Flanged Fittings, and Valves (ASA No. B16e5—1943) and clarify the time of testing, namely, after rough machining. This is the only problem in Specifications A 157, whereas in the other two emergency provisons, new grades are being added. In the more general specifications A 95, a new grade with tensile strength of 65,000 psi.; yield point, 35,000 psi.; elongation in 2 in., 20 per cent; a reduction of area, 30 per cent, is being set up. A grade with similar properties, but with modified chemistry is being established in Specifications A 216 which covers carbon-steel material suitable for fusion welding for service up to 850 F. In the latter specifications, two existing emergency grades for pressure-containing turbine castings are continued, the new grade EWCB being considered suitable for valves, flanges, and fittings.

TENTATIVE STANDARD APPROVED DURING THE PAST YEAR

On the recommendation of Committee A-1, new Tentative Specifications for Carbon-Steel Seamless Drum Forgings (A 266 - 43 T) were accepted[1] by Committee E-10 on Standards on November 17, 1943. These specifications cover three grades of carbon-steel hollow drums and headers for use in boilers and for other pressure vessels and also for forgings for heads, covers, and plugs when forgings are desired for these parts. They were developed in a special section of Subcommittee VI on Steel Forgings, under the chairmanship of A. O. Schaefer, The Midvale Co., and serving with him were other producers and leading consumers of these products.

While the specifications are partly an outgrowth of work on forgings in the National Emergency Steel Specifications Project, it has been evident for some time that an A.S.T.M. standard would fill a gap in the group of A.S.T.M. specifications that are embodied in the materials section of the A.S.M.E. Boiler Code and which might supersede Specifications S-4. This was the only item in the materials section of the code which was not an A.S.T.M. specification. Specifications A 266 are more than a counterpart of Specifications S 4, since they cover auxiliary forgings and a number of requirements have been brought in line with latest manufacturing and fabricating techniques. In the development of the requirements there was evident a desire on the part of some users to include a definite restriction on the amount of aluminum which might be used in killing the steel even though no previous requirements had been considered. The final decision, somewhat of a compromise, met the approval of those concerned with the specifications. Briefly, this involves a requirement on grain size where the material is to be used at temperatures above 800 F. The McQuaid-Ehn grain size must fall in a range from 1 to 5.

RECOMMENDATIONS ON SPECIFICATIONS

The numerous specifications affected by recommendations submitted in this report to the Society are listed in Table I, which also records the committee vote. The recommendations being presented are detailed in the Appendix, with some explanations of the reasons for the proposals.

Reaffirmation of Specifications.—The various subcommittees have revised several standard specifications, which by the 1945 Annual Meeting would have stood six years or more without revision, and several tentative specifications which have remained in the tentative status two years or longer without revision. Subcommittee II on Structural Steel for Bridges, Buildings and Rolling Stock has asked Committee A-1 to reaffirm five of its specifications, and the results of the letter ballot vote are recorded in Table I. Even though one of these specifications, A 7, covering structural steel for bridges and buildings, perhaps the most widely used A.S.T.M. standard, was modified in 1942, the subcommittee still wishes to have them reaffirmed at this time.

Each of the subcommittees has reviewed its specifications, keeping in mind the 1944 publication date of the Book of

---

[1] In submitting this recommendation to Committee E-10 on Standards Committee A-1 reported results of the letter ballot vote as follows: Of a total membership of 235, 138 members returned their ballots, of whom 76 voted affirmatively, 0 negatively, and 62 members marked their ballots "not voting."

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items Specifications for the materials indicated	Affirmative	Negative	Ballots Marked "Not Voting"
I. REVISIONS OF TENTATIVE STANDARDS			
Light Gage Structural Quality Flat Hot-Rolled Carbon Steel (0.2499 and 0.1874 in. to 0.0478 in. in Thickness) (A 245 - 42 T)	98	0	75
Light Gage Structural Quality Flat-Rolled Carbon Steel (0.0477 to 0.0225 in. in Thickness) (A 246 - 42 T)	98	0	75
Alloy-Steel Bolting Materials for High-Temperature Service from 750 to 1100 F., Metal Temperatures (A 193 - 40 T)	87	5	81
Heat-Treated Carbon-Steel Bolting Material (A 261 - 43 T)	89	4	80
Lap-Welded and Seamless Steel Pipe for High-Temperature Service (A 106 - 43 T)	96	0	77
Seamless Alloy-Steel Pipe for Service at Temperatures from 750 to 1100 F. (A 158 - 42 T)	95	0	78
Seamless Carbon-Molybdenum Alloy-Steel Pipe for Service at Temperatures from 750 to 1000 F. (A 206 - 42 T)	94	0	79
Carbon-Steel Castings Suitable for Fusion Welding for Service at Temperatures from 750 to 1100 F. (A 216 - 42 T)	102	1	78
Alloy-Steel Castings Suitable for Fusion Welding for Service at Temperatures from 750 to 1100 F. (A 217 - 42 T)	102	1	78
II. TENTATIVE REVISIONS OF STANDARDS			
Alloy-Steel Forgings for General Industrial Use (A 237 - 42)	105	0	68
Carbon-Steel and Alloy-Steel Ring and Disk Forgings (A 243 - 43)	95	0	78
III. REVISIONS OF STANDARDS, IMMEDIATE ADOPTION			
Carbon-Steel Bars for Springs (A 14 - 42)	87	2	85
Carbon-Steel Bars for Springs, with Special Silicon Requirements (A 68 - 39)	87	2	85
Welded and Seamless Steel Pipe (A 53 - 42)	90	0	91
Black and Hot-Dipped Zinc-Coated (Galvanized) Welded and Seamless Steel Pipe for Ordinary Uses (A 120 - 42)	90	0	91
Low - Carbon Nickel - Steel Plates for Boilers and Other Pressure Vessels (A 203 - 42)	92	0	81
Molybdenum-Steel Plates for Boilers and Other Pressure Vessels (A 204 - 42)	96	0	77
Boiler and Firebox Steel for Locomotives (A 30 -42)	94	0	79
Carbon-Steel Plates for Stationary Boilers and Other Pressure Vessels (A 70 - 42)	98	0	74
Carbon-Silicon Plates of Ordinary Tensile Ranges for Fusion-Welded Boilers and Other Pressure Vessels (A 201 - 43)	93	0	80
III. REVISIONS OF STANDARDS, IMMEDIATE ADOPTION—*Cont'd*			
Chrome - Manganese - Silicon (CMS) Alloy-Steel Plates for Boilers and Other Pressure Vessels (A 202 - 39)	88	0	85
High Tensile Strength Carbon-Silicon Steel Plates for Boilers and Other Pressure Vessels (Plates 4½ in. and Under in Thickness) (A 212 - 39)	95	0	78
Alloy-Steel Bolting Material for High-Temperature Service (A 96 - 39)	89	0	84
Multiple-Wear Wrought Steel Wheels (A 57 - 39)	68	0	89
Heat-Treated Wrought Steel Wheels (A 244 - 42)	68	0	89
Lap-Welded and Seamless Steel and Lap-Welded Iron Boiler Tubes (A 83 - 44)	92	0	89
Electric - Resistance - Welded Steel and Open-Hearth Iron Boiler Tubes (A 178 - 44)	92	0	89
Spiral-Welded Steel or Iron Pipe (A 211 - 44)	92	0	89
Electric - Resistance - Welded Steel Heat-Exchanger and Condenser Tubes (A 214 - 44)	92	0	89
Electric - Resistance - Welded Steel Boiler and Superheater Tubes for High-Pressure Service (A 226 - 44)	92	0	89
Electric - Resistance - Welded Carbon-Molybdenum Alloy-Steel Boiler and Superheater Tubes (A 250 - 44)	92	0	89
Seamless Low-Carbon and Carbon-Molybdenum Steel Still Tubes for Refinery Service (A 161 - 40)	94	0	87
Seamless Cold-Drawn Intermediate Alloy-Steel Heat-Exchanger and Condenser Tubes (A 199 - 40)	94	0	87
Seamless Intermediate Alloy-Steel Still Tubes for Refinery Service (A 200 - 40)	94	0	87
Seamless Carbon-Molybdenum Alloy-Steel Boiler and Superheater Tubes (A 209 - 42)	94	0	87
Medium-Carbon Seamless Steel Boiler and Superheater Tubes (A 210 - 40)	94	0	87
Seamless Alloy-Steel Boiler and Superheater Tubes (A 213 - 42)	94	0	87
Electric - Resistance - Welded Steel Pipe (A 135 - 42)	94	0	87
Seamless Cold-Drawn Low-Carbon Steel Heat-Exchanger and Condenser Tubes (A 179 - 42)	94	0	87
Seamless Steel Boiler Tubes for High-Pressure Service (A 192 - 40)	94	0	87
Atomic - Hydrogen - Arc - Welded and Electric-Resistance - Welded Alloy-Steel Boiler and Superheater Tubes (A 249 - 42)	92	0	89
Factory-Made Wrought Carbon-Steel and Carbon-Molybdenum-Steel Welding Fittings (A 234 - 42)	88	0	93
Forged or Rolled Alloy-Steel Pipe Flanges, Forged Fittings, and Valves and Parts for Service at Temperatures from 750 to 1100 F. (A 182 - 40)	87	0	94

TABLE I.—*Concluded*

Items	Affirmative	Negative	Ballots Marked "Not Voting"
III. REVISIONS OF STANDARDS, IMMEDIATE ADOPTION—*Cont'd*			
Carbon-Steel Castings for Miscellaneous Industrial Uses (A 27 - 42)	113	1	67
Carbon-Steel and Alloy-Steel Castings for Railroads (A 87 - 42)	113	1	67
Carbon-Steel Castings for Valves, Flanges, and Fittings for High-Temperature Service (A 95 - 41)	102	1	78
Alloy-Steel Castings for Structural Purposes (A 148 - 42)	113	1	67
Alloy - Steel Castings for Valves, Flanges, and Fittings for Service at Temperatures from 750 to 1100 F. (A 157 - 42)	102	1	78
Carbon-Steel Castings Suitable for Fusion Welding for Miscellaneous Industrial Uses (A 215 - 41)	113	1	67
IV. ADOPTION OF TENTATIVE STANDARDS AS STANDARD			
Manganese-Vanadium Steel Plates for Boilers and Other Pressure Vessels (A 225 - 39 T), as revised	82	0	91
Welded Alloyed Open-Hearth Iron Pipe (A 253 - 42 T), as revised	93	0	79
Welded and Seamless Steel Pipe Piles (A 252 - 42 T), as revised	80	0	101
Copper-Brazed Steel Tubing (A 254 - 42 T)	79	0	102
V. WITHDRAWAL OF STANDARDS			
Carbon-Steel and Alloy-Steel Blooms, Billets, and Slabs for Forgings (A 17 - 29)	105	0	68
Forge-Welded Steel Pipe (A 136 - 34)	93	0	80
Riveted Steel and Wrought-Iron Pipe (A 138 - 34)	86	0	87
VI. REAFFIRMATION OF STANDARDS			
Steel for Bridges and Buildings (A 7 - 42)	107	0	66
Structural Nickel Steel (A 8 - 39)	99	0	74
Mild Steel Plates (A 10 - 39)	110	0	63
Structural Silicon Steel (A 94 - 39)	100	0	73
Structural Rivet Steel (A 141 - 39)	99	0	74
One-Wear and Two-Wear Wrought Steel Wheels (A 186 - 39)	68	0	89
Steel Tires (A 26 - 39)	68	0	89

Standards. In some cases the fact that emergency alternate provisions are in effect, thus to all intents and purposes modifying the standard requirements, has led the committees to continue a few specifications without change. Unquestionably, when the war emergency is over, some changes in the regular specifications will ensue.

NOTES ON SOME ACTIVITIES OF GENERAL INTEREST AND ALSO ON SPECIFIC COMMITTEE PROJECTS

The following notes are intended to give some idea of current projects being developed in Committee A-1 on Steel, some being of over-all interest; others being carried on in specific subcommittees and thus of interest to particular groups.

Reorganization of the Committee:

There have been discussions in the Advisory Committee of the possibility of rearranging the subcommittee structure so that all specification work in a certain field, for example on castings or on forgings, would be assigned to one subcommittee, thus avoiding overlapping jurisdiction which is now present in several activities. At the same time, the committee is considering the relationship of its work to that of other standing committees in the ferrous metals field.

Magnetic Particle Testing:

Although there has been greatly increased interest and concern with magnetic particle testing and inspection in connection with many steel products, one particular problem has been of immediate concern, namely, the use of emergency specifications covering certain turbine and generator parts where magnetic particle testing is required. Obviously a standardized procedure and some general recommendations are desirable and also uniform practice with respect to interpretation would be salutary from the standpoint of both the producer and consumer of the material. To develop a recommended practice, a special section was appointed with the consent of the Society's Executive Committee, in June, 1943. To those concerned with heavy forgings a draft of the procedure is being distributed. Meanwhile, definite interest has been expressed in the field of steel castings and another group has drafted a recommended procedure involving magnetic particle inspection of steel castings. Coordination of the various thoughts and practices must be considered. With so many different techniques being used, it is quite obvious that some authoritative statements in this field would be constructive.

Tests for Hardenability of Steel:

The Special Subcommittee on Hardenability, E. W. Upham, *chairman*, has been following developments in connection with the very widespread use of the End-Quench Test for Hardenability of Steel (A 255 – 42 T) which includes a description of the method and necessary equipment, and an arithmetic chart for plotting hardenability curves. Some minor changes were made in the chart when it was last reprinted in order to facilitate the recording of data. Some additional proposals have been made relating to the design of the chart and these are being considered by the subcommittee.

Steel Rails and Accessories:

In order to utilize heats made in connection with war orders, which would comply with all requirements of the Specifications for Quenched Carbon-Steel Joint Bars (A 49 – 39), except manganese, it had been proposed to issue an emergency provision permitting an increase in the manganese content from "0.80" to read "1.00" max. per cent. Following correspondence in Subcommittee I and contacts with the American Railway Engineering Association with which the manufacturers also had been in touch, it was decided to lay this matter on the table pending an investigation of bars with higher manganese. Whether, with higher permissible manganese, the optional bend test should be made mandatory is one of the questions involved.

Structural Steel for Bridges, Buildings, and Rolling Stock:

Some time ago interest in weldability of structural steel and the possibility of establishing specification requirements led to the organization of a section which developed proposed requirements including limitations on carbon and manganese with diminished physical properties as thickness increased. No action was taken on the proposals but now there is renewed interest in the subject and this section will renew its studies in cooperation with Subcommittee XXV on Welding of Steel.

Steel Forgings:

Emergency Specifications for Heavy Forgings.—Increasing use of the seven emergency specifications (ES – 21 to ES – 27, inclusive) covering heavy forgings for turbine and generator application and consequent desirability of changing the status of these to regular A.S.T.M. tentative standards has resulted in the formation of a special section under the chairmanship of N. L. Mochel. This section will give consideration to such changes in the specifications as may be necessary; and when agreement is reached to make appropriate recommendations to Subcommittee VI looking toward action at the June meeting or through Committee E-10 on Standards and possible publication of the specifications as tentative in the 1944 Book of Standards.[1] The development of these emergency specifications in a relatively short time to expedite production of some of our most strategic products has been considered a most constructive effort and although the work was done through a National Emergency Steel project, a preponderance of the membership was active in Subcommittee VI. There has been a tremendous reduction in the various chemical analyses of steels used, standard tests have been agreed upon, and as a result of the meetings and discussions, there has come about a much better understanding of mutual problems by the consumer and producer.

---

[1] See Editorial Note, p. 71.

Welding.—Discussion of the justification of establishing certain specific requirements involving welding conditions of forgings which are covered by the Standard Specifications for Carbon-Steel and Alloy-Steel Ring and Disk Forgings (A 243 - 43) limiting, as is usually the case, the carbon and manganese content, resulted in a decision to make no change. At present, the specifications do not include a requirement for carbon (only manganese, phosphorus, and sulfur) but agreement between the manufacturer and the purchaser may be invoked for other elements including, particularly, of course, the various alloys going into the alloy steels.

Miscellaneous.—For some unknown reason, when the emergency provisions EA - A 236a on Carbon-Steel Forgings for Locomotives and Cars were established providing for new classes *H* and *I* for quenched-and-tempered forgings with relatively high physical properties, the smaller size classifications, up to 4 in. and from 4 to 7 in. in diameter were not included. The section in charge is being asked to review this and make recommendations.

A special section under the chairmanship of L. H. Fry has been asked to study and report on questions involving a clause providing for retests in case of defective specimens.[1]

Material for Reforging.—A most important current activity in the field of forgings involves a clarification and recommendation of newer developments on the requirements for blooms, billets, slabs, etc., for reforging purposes.

In 1939 and 1940, very intensive work in four special sections was carried out leading to the publication of four specifications A 235 through A 238, covering carbon- and alloy-steel forgings for industrial and railroad use, thus clarifying a rather chaotic specification situation. At the same time it was realized the requirements on materials for reforging purposes should be modernized which led to the development of Tentative Specifications for Blooms, Billets, and Slabs for Reforging Purposes (A 248 - 41 T). With the war came the necessity of making every move to expedite production of heavy forgings used in generator and turbine work, shafts, etc., which led to the development of Emergency Specifications ES - 21 to ES - 27. Also involved was the necessity of further clarification of materials for reforging particularly applicable to these emergency specifications and a joint NESS section had drafted proposals which it was subsequently developed might appropriately be expanded. A conference in November of those concerned, including the officers of Committee A-1 and Subcommittee VI, authorized the appointment of a special section headed by L. E. Ekholm with A. O. Schaefer as vice-chairman to draft a standardized and consolidated specification on blooms, billets, and slabs, this to incorporate specific chemistry requirements, permissible tolerances on chemistry, and where specially invoked, certain supplementary requirements are to be included such as incidental alloy content, restricted chemical composition, discard, homogeneity tests, hardenability, inclusion requirements, etc. Intensive work on the part of Messrs. Ekholm and Schaefer resulted in a draft which was distributed to the section and discussed at length in Cincinnati. This resulted in two specifications and these are now being prepared and will be submitted to the section and Subcommittee VI for approval and it is hoped will appear in the 1944 Book of Standards.[1]

Steel Castings:

In addition to the problem of magnetic particle testing and inspection, as discussed previously in this report, there is another perplexing matter on which a special section is conducting studies—that of stray, residual elements in castings, which, because of the current war situation has been a matter of increasing concern, particularly as it involves the weldability of steel. There was extended discussion of this problem at the March meeting in Cincinnati, and although no decision was reached, there was a constructive airing of various viewpoints. Also a special section to investigate the matter was authorized.

Steel Tubing and Pipe:

Wall Thickness of Double Extra Strong Pipe.—As a result of discussions in Subcommittee IX, the manufacturers of double extra strong pipe, covered in the Specifications for Welded and Seamless Steel Pipe (A 53 - 42) and for Black and Hot-Dipped Zinc-Coated (Galvanized) Welded and Seamless Steel Pipe for Ordinary Uses (A 120 - 42) have been considering a proposal to set up reduced wall thicknesses which would conform essentially to those of schedule 160 material. Recommendations from those producing these materials are expected.

Electric-Resistance-Welded Tubing.—As a result of extended discussion at the March meeting of Subcommittee IX concerning failures in certain refinery operations of electric-resistance-welded tubing, a special committee of consumers and producers was appointed to investigate this matter, and at an extended two-day meeting developed certain recommendations which are being given further consideration. Eventually they will result in modifications in some of the applicable specifications. Apparently some of the tubing which was furnished was not purchased in accordance with standard requirements, and was used only because of the emergency situation.

Modifications in Chemical Requirements of Certain Austenitic Steels.—Either as an emergency or a regular recommendation, some of the requirements as to chemical composition involving the straight 18 per cent chromium, 8 per cent nickel steel, and the modified composition with molybdenum (for example, grades *T 8* and *T 20*, respectively in tube specifications A 213) need modification. It was decided that the joint committee preparing specifications for stainless pipe and tubing for pressure applications would be asked to make recommendations.

Stainless Tubing.—The joint subcommittee headed by J. J. B. Rutherford has held certain meetings and there is substantial agreement on proposed specifications for stainless tubing for applications in the food and dairy industries, for general purposes, and also material for use in the oil refinery field.[1] This work is being carried on as a joint activity of Committee A-1 and Committee A-10 on Iron-Chromium, Iron-Chromium-Nickel and Related Alloys.

Service at High Temperatures of Deoxidized Acid-Bessemer Seamless Pipe.—Work is under way by a number of pipe fabricators on obtaining information through shop fabrication tests on properties of deoxidized acid-bessemer seamless pipe. A joint subcommittee consisting of members from Subcommittee IX on Steel Tubing and Pipe and Subcommittee XXII on Valves, Fittings, Piping and Flanges for High-Temperature Service, under the chairmanship of A. Hurtgen, is attempting to correlate data and information. A series of tests have been carried out at the National Bureau of Standards on behalf of the U. S. Coast Guard which is concerned with certain problems. At the Spring Meeting in March through the courtesy of the Coast Guard an informal report was submitted. The pipe fabricators have not completed their extensive work but a report is anticipated. The joint group, it is hoped, can have a complete report for the June, 1944, meeting. Some comments on this report will appear in the 1945 Committee A-1 Report. Essentially the report indicated that the investigation in so far as the scope was concerned showed no reason to delete acid-bessemer seamless pipe from the Standard Specifications A 53 (Welded and Seamless Steel Pipe) or A 106 (Lap-Welded and Seamless Steel Pipe for High-Temperature Service) because of fabrication difficulties or other causes which the subgroup investigated.

Rounding Off Decimals:

Because of the lack of uniformity in certain specifications and among the various subcommittees of Committee A-1 with respect to rounding off decimals which extend beyond three figures, Subcommittee IX on Steel Tubing and Pipe voted to embody the principles covered in the A.S.T.M. Recommended Practices for Designation of Numerical Requirements in Standards (E 29 - 40 T). In line with this action, certain editorial changes are being made in the Standard Specifications for Welded and Seamless Steel Pipe (A 53 - 42) and in the Emergency Alternate Provisions for Electric-Fusion-Welded Steel Pipe (EA - A 139a).

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, N. L. Mochel.
Vice-Chairman, H. B. Oatley.
Vice-Chairman, J. O. Leech.
Secretary, R. J. Painter.

This report has been submitted to letter ballot of the committee which consists of 242 members; 170 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

N. L. MOCHEL,
Chairman.

H. P. BIGLER,
Secretary,
R. J. PAINTER,
Staff Assistant.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee A-1 presented the following recommendations to the Society through Committee E-10 on Standards:

Tentative Specifications for:

Carbon-Steel Blooms, Billets, Slabs for Forgings (A 273 - 44 T),
Alloy-Steel Blooms, Billets, Slabs for Forgings (A 274 - 44 T) and Emergency Alternate Provisions EA - A 274,

Tentative Methods for:

Magnetic Particle Testing of Commercial Steel Castings (A 272 - 44 T),
Magnetic Particle Testing and Inspection of Heavy Forgings (A 275 - 44 T),

Withdrawal of Tentative Specifications for:

Carbon-Steel and Alloy-Steel Blooms, Billets, and Slabs for Forgings (A 248 - 41 T),

Revision of Tentative Specifications for:

Seamless Alloy-Steel Pipe for Service at Temperatures from 750 to 1100 F. (A 158 - 42 T),
Carbon-Steel Seamless Drum Forgings (A 266 - 43 T),

Tentative Revision of Standard Specifications for:

Steel for Bridges and Buildings (A 7 - 42),
Mild Steel Plates (A 10 - 39),
Low Tensile Strength Carbon-Steel Plates of Structural Quality for Welding (A 78 - 43),
Low-Alloy Structural Steel (A 242 - 42),

Carbon-Steel Forgings for General Industrial Use (A 235 - 42),
Carbon-Steel Forgings for Locomotives and Cars (A 236 - 42),
Alloy-Steel Forgings for General Industrial Use (A 237 - 42),
Alloy-Steel Forgings for Locomotives and Cars (A 238 - 42),
Carbon-Steel and Alloy-Steel Ring and Disk Forgings (A 243 - 43),
Electric-Fusion-Welded Steel Pipe (Sizes 8 in. to but not Including 30 in.) (A 139 - 42),
Commercial Quality Hot-Rolled Bar Steels (A 107 - 42),
Commercial Cold-Finished Bar Steels and Cold-Finished Shafting (A 108 - 36),

Revision of Emergency Alternate Provisions in

Tentative Specifications for Seamless Alloy-Steel Pipe for Service at Temperatures from 750 to 1100 F. (EA - A 158a),
Standard Specifications for Carbon-Steel Plates for Stationary Boilers and Other Pressure Vessels (EA - A 70b),
Standard Specifications for Seamless Alloy-Steel Boiler and Superheater Tubes (EA - A 213a),
Standard Specifications for Atomic-Hydrogen-Arc-Welded and Electric-Resistance-Welded Alloy-Steel Boiler and Superheater Tubes (EA - A249a),

Withdrawal of Emergency Alternate Provisions in

Standard Specifications for Steel Tie Plates (EA - A 67),
Standard Specifications for Hot-Worked High-Carbon Steel Tie Plates (EA - A 241),
Standard Specifications for Boiler and Firebox Steel for Locomotives (EA - A 30),
Standard Specifications for Carbon-Silicon Steel Plates of Ordinary Tensile Ranges for Fusion-Welded Boilers and Other Pressure Vessels (EA - A 201),
Standard Specifications for Chrome-Manganese-Silicon (CMS) Alloy-Steel Plates for Boilers and Other Pressure Vessels (EA - A 202),
Standard Specifications for Low-Carbon Nickel-Steel Plates for Boilers and Other Pressure Vessels (EA - A 203),
Standard Specifications for Molybdenum-Steel Plates for Boilers and Other Pressure Vessels (EA - A 204), and
Standard Specifications for High Tensile Strength Carbon-Silicon Steel Plates for Boilers and Other Pressure Vessels (Plates 4½ in. and Under in Thickness) (EA - A 212).

All of these recommendations were accepted by Committee E-10 on August 28, 1944, and the new and revised tentatives and emergency alternate provisions appear in the 1944 Book of A.S.T.M. Standards, Part I.

On October 25, 1944, the Standards Committee accepted the following recommendations submitted by Committee A-1 and Committee A-10 on Iron-Chromium, Iron-Chromium-Nickel and Related Alloys, as joint sponsors:

New Tentative Specifications for:

Seamless and Welded Ferritic Stainless Steel Tubing for General Service (A 268 - 44 T) and Emergency Alternate Provisions EA - A 268,
Seamless and Welded Austenitic Stainless Steel Tubing for General Service (A 269 - 44 T) and Emergency Alternate Provisions EA - A 269,
Seamless and Welded Austenitic Stainless Steel Tubing for Dairy and Food Industry (A 270 - 44 T) and Emergency Alternate Provisions EA - A 270, and
Seamless Austenitic Chromium-Nickel Steel Still Tubes for Refinery Service (A 271 - 44 T) and Emergency Alternate Provisions EA - A 271.

The new tentative specifications and emergency alternate provisions appear in the 1944 Book of A.S.T.M. Standards, Part I.

On October 30, 1944, Committee E-10 accepted proposed revisions in Emergency Alternate Provisions EA - A 1 applying to the Standard Specifications for Open-Hearth Carbon-Steel Rails (A 1 - 39). The revised emergency provisions appear in the 1944 Book of A.S.T.M. Standards, Part I, under the designation EA - A 1a.

Revisions in the Emergency Specifications for Carbon-Steel Forgings for Rings for Main Reduction Gears (ES - 23) were accepted by the Standards Committee on December 11, 1944. The revised emergency specifications under the designation ES - 23a appear in the 1944 Book of A.S.T.M. Standards, Part I.

APPENDIX

RECOMMENDATIONS AFFECTING STANDARDS FOR STEEL

In this Appendix recommendations are given affecting certain specifications, both standard and tentative, covering various steel products. These specifications appear in their present form in either the 1942 Book of A.S.T.M. Standards, Part I, or the 1943 Supplement, Part I, as indicated by the final number in the A.S.T.M. designation.

Specifications for Steel Castings.—In each of the following eight specifications covering various types of steel castings add a reference to the new A.S.T.M. methods for magnetic particle inspection:

A 27 - 42
A 87 - 42
A 95 - 41
A 148 - 42
A 157 - 42
A 215 - 41
A 216 - 42 T
A 217 - 42 T

In the above specifications the reference is to appear in a separate section and reads as follows:

> *Magnetic Particle Testing.*—If specified in the inquiry, contract or order, and when mutually agreed upon by the manufacturer and purchaser, castings ordered to these specifications may be subject to magnetic particle inspection. When so specified the magnetic particle inspection shall be in accordance with the Tentative Methods of Magnetic Particle Testing of Commercial Steel Castings (A.S.T.M. Designation: A 272).

Marking Clause in Pipe and Tubing Specifications.—In the following eighteen specifications for pipe and tubing change the marking clause so that the hydrostatic test pressure need not be indicated, but requiring the marking to include the symbols A.S.T.M.; also delete the word "Specification" if now required:

A 53 - 42
A 83 - 42
A 120 - 42
A 161 - 40
A 178 - 40
A 179 - 42
A 192 - 40
A 199 - 40
A 200 - 40
A 209 - 42
A 210 - 40
A 211 - 40
A 213 - 42
A 214 - 42
A 226 - 40
A 249 - 42
A 250 - 43
A 253 - 42 T

Elongation and Flattening Test in Pipe and Tubing Specifications.—In the following eight specifications for pipe and tubing a change is recommended in the provisions regarding modifications in elongation with decrease in wall thickness; also in each specification a formula for calculating the distance between the plates in the flattening test is recommended for inclusion. The accompanying Table I gives the permissible modifications for elongation that are recommended for inclusion in the respective specifications indicated and also gives values for the constant "e" used in the formula for the flattening test:

A 161 - 40
A 199 - 40
A 200 - 40
A 209 - 42
A 210 - 40
A 213 - 42
A 135 - 42
A 192 - 40

In each of the above specifications the section on flattening test is to be revised to read as follows, except that the value for "e" is to be as shown in the accompanying Table I:

> *Flattening Test.*—7. (*a*) A section of the tube, not less than 2½ in. in length, shall be flattened cold between parallel plates until the opposite walls of the tube meet. No cracks or breaks in the metal shall occur until the distance between the plates is less than the calculated value of H by the following formula:

$$H = \frac{(1 + e)t}{e + t/D}$$

where:

H = distance between flattening plates in inches,

e = deformation per unit length (constant for a given grade of steel, 0.09[a] for the low-carbon grade and 0.08[a] for the carbon-molybdenum grade),

t = nominal wall thickness of tube in inches, and

D = actual outside diameter of tube in inches.

(*b*) Evidence of laminations or burnt material shall not develop during the entire flattening process.

TABLE I.

Spec. No. and Grade	Deduction for Each $\frac{1}{32}$ in. Decrease in Thickness Below $\frac{5}{16}$ in. from the Basic Minimum, per cent	Values of Constant *e* for Flattening Test Formula
A 161		
Low Carbon	1.75	0.09
Carbon Molybdenum	1.50	0.08
A 199		
(All Grades)	1.50	0.08
A 200		
(All Grades)	1.50	0.08
A 209		
Carbon Molybdenum	....	....
All Grades	1.50	0.08
A 210		
Carbon	1.25	0.07
A 213		
Ferritic	1.50	0.08
Austenitic	1.75	0.09
A 135		
Grade A	1.75	....
Grade B	1.50	....

REVISIONS OF TENTATIVE STANDARDS

Tentative Specifications for Light Gage Structural Quality Flat Hot-Rolled Carbon Steel (0.2499 and 0.1874 in. to 0.0478 in. in Thickness) (A 245 – 42 T):

To eliminate confusion on the direction in which the bend test specimen is to be taken, and to clarify Sections 6, 9, and 10, on check analysis, test specimens, and number of tests, the following changes are proposed in these specifications:

Section 6.—In line 3 change the word "lot" to read "each lot."

Section 9.—Add a new Paragraph (*d*) to read as follows: "(*d*) The bend test specimens for grade C shall have their longest axis in the direction of last hot rolling."

Section 10 (*a*).—In line 4 change the word "lot" to read "from each lot."

Tentative Specifications for Light Gage Structural Quality Flat-Rolled Carbon Steel (0.0477 to 0.0225 in. in Thickness) (A 246 – 42 T):

Sections 6, 9 and 10.—Make the same changes in these sections as recommended above for Sections 6, 9 and 10, of Specifications A 245.

Tentative Specifications for Alloy-Steel Bolting Materials for High-Temperature Service from 750 to 1100 F., Metal Temperatures (A 193 – 40 T):

Table I.—To bring the chemistry of the chromium-molybdenum steel (B 7) in line with the latest industrial practice and to have a range consistent with those commercially recognized, change the chemical composition requirements of grade B 7 in Table I to read as prescribed in the following table:

	Present Values	Revised Values
Carbon, per cent	0.35 to 0.45	0.33 to 0.47
Manganese, per cent	0.60 to 0.90	0.66 to 1.04
Phosphorus, max., per cent	0.04	0.045
Sulfur, max., per cent	0.05	0.055
Silicon, per cent	0.15 to 0.30	0.18 to 0.37
Nickel, per cent	....	....
Chromium, per cent	0.80 to 1.10	0.75 to 1.15
Molybdenum, per cent	0.15 to 0.25	0.13 to 0.27
Tungsten, per cent	....	....
Vanadium, per cent	....	....

---

[a] These values of *e* are for Specifications A 161; the values to be inserted in the other specifications are given in Table I.

There has been considerable discussion on the necessity of including in these specifications tolerances for the bar stock and also dimensional requirements on heads of bolts. The following revisions in Section 12 are a compromise of the different opinions on these subjects.

Section 12.—Change from its present form to read as follows:

12. (*a*) Bolts, screws, studs, and stud bolts shall be pointed and shall have a workmanlike finish.

(*b*) Standard permissible variations for dimensions shall be as set forth in Table II.

TABLE II.—PERMISSIBLE VARIATIONS IN SIZE OF HOT-ROLLED BARS.

Specified Size, in.	Permissible Variations from Specified Size, in.		Out-of-Round, in.
	Over	Under	
5/16 and under	0.005	0.005	0.008
Over 5/16 to 7/16, incl.	0.006	0.006	0.009
Over 7/16 to 5/8, incl.	0.007	0.007	0.010
Over 5/8 to 7/8, incl.	0.008	0.008	0.012
Over 7/8 to 1, incl.	0.009	0.009	0.013
Over 1 to 1-1/8, incl.	0.010	0.010	0.015
Over 1-1/8 to 1-1/4, incl.	0.011	0.011	0.016
Over 1-1/4 to 1-3/8, incl.	0.012	0.012	0.018
Over 1-3/8 to 1-1/2, incl.	0.014	0.014	0.021
Over 1-1/2 to 2, incl.	1/64	1/64	0.023

(*c*) Headed bolts shall be semifinished, hexagonal or square in shape, and in accordance with the dimensions for the regular or heavy series, as required, of the American Standard for Wrench-Head Bolts and Nuts and Wrench Openings (ASA No. B18.2 - 1941). Unless otherwise specified, the American Standard heavy hexagon series shall be used.

Section 17. — Change the marking clause as recommended earlier in this Appendix.

Tentative Specifications for Heat-Treated Carbon-Steel Bolting Material (A 261 - 43 T):

Section 14.—Make the same changes in this section as recommended above in Section 12 of Specifications A 193.

Tentative Specifications for:
Lap-Welded and Seamless Steel Pipe for High-Temperature Service (A 106 - 43 T),
Seamless Alloy-Steel Pipe for Service at Temperatures from 750 to 1100 F. (A 158 - 42 T),
Seamless Carbon-Molybdenum Alloy-Steel Pipe for Service at Temperatures from 750 to 1000 F. (A 206 - 42 T):

In order that these three specifications which are specifically applicable to pipe, may be used for the purchase of header tubes, and in order that certain sizes used in tube designations which are foreign to the pipe field be included in the tables covering permissible variations in outside diameter (Sections 13 (*b*), 16 (*b*), and 17 (*b*) respectively) the following revised table is recommended. This does not change the requirements on pipe, but merely modifies the ranges of nominal diameters so that they cover tube sizes.

Nominal Pipe Size, in.	Permissible Variations in Outside Diameter, in.	
	Over	Under
1/8 to 1½, incl.	1/64 (0.015)	1/32 (0.031)
Over 1½ to 4, incl.	1/32 (0.031)	1/32 (0.031)
Over 4 to 8, incl.	1/16 (0.062)	1/32 (0.031)
Over 8 to 18, incl.	3/32 (0.093)	1/32 (0.031)
Over 18 to 24, incl.	1/8 (0.125)	1/32 (0.031)

In Specifications A 106 add the following as a new Paragraph 14 (*c*): "(*c*) If definite lengths are not required, pipe may be ordered in single random lengths of 16 to 22 ft. with 5 per cent 12 to 16 ft., or in double random lengths with a minimum average of 35 ft. and a minimum length of 22 ft. with 5 per cent 16 to 22 ft."

In Specifications A 158 make the following changes:

Table I.—Change the manganese content of grade P 8b from the present "3.0" to read "2.0" per cent; minimum percentage of titanium when added, to be "five times the carbon content with a maximum of 0.60 per cent"; and the minimum percentage of columbium, when added,

to be "ten times carbon content with a maximum of 1.0 per cent."

Also, change the composition of grade P 8a as follows: Increase the carbon content from the present "0.07" to "0.08 per cent max."; chromium content range from "17.00 to 20.00" to "18.00 to 20.00 per cent."

TENTATIVE REVISIONS OF STANDARDS

Standard Specifications for Alloy-Steel Forgings for General Industrial Use (A 237 – 42):

Section 1 (b).—Add a reference to two new classes (G and H) of normalized, quenched and tempered alloy-steel forgings, making line 10 to read as follows: "Classes D, E, F, G, and H."

Table I.—Add two new classes, G and H, with requirements as follows:

Class	Size				Tensile Strength, min., psi.	Yield Point, min., psi.	Elongation in 2 in., min., per cent	Reduction of Area, min., per cent
	Solid Diameter or Thickness		Bored Wall Thickness, in.					
	Over	Not Over	Over	Not Over				
G (Normalized, Quenched, and Tempered)	..	4	..	2	145 000	120 000	15	45
	4	7	2	3½	140 000	115 000	14	40
	7	10	3½	5	135 000	110 000	13	40
H (Normalized, Quenched, and Tempered)	..	4	..	2	170 000	140 000	13	40
	4	7	2	3½	165 000	135 000	12	35
	7	10	3½	5	160 000	130 000	11	35

Section 10 (e).—Add a reference to two new classes (G and H) of forgings, making line 2 to read as follows: "Table I for classes D, E, F, G, and H forgings."

Section 11 (b).—Add a reference to the new class G forgings, making line 3 read as follows: "8-in. wall, and for classes F and G, all sizes, the."

Section 11.—Add a new Paragraph to (*c*) this section to read as follows: "(*c*) For class H forgings no bend test shall be required."

Section 14.—Omit Paragraph (*b*) relating to crystalline fracture.

Standard Specifications for Carbon-Steel and Alloy-Steel Ring and Disk Forgings (A 243 – 43):

Section 10 (e).—Add a reference to two new classes (N and O) of forgings making line 2 read as follows: "Table II for classes G, K, L, M, N, and O."

Section 11 (b).—Add a reference to the new class N forgings, making line 1 read as follows: "For classes L, M, and N forgings, the."

Section 11.—Add a new Paragraph (*c*) to this section to read as follows: "(*c*) For class O forgings no bend test shall be required".

Table II.—Add at the end of the table two new classes, N and O, with requirements as follows:

Class	Size		Tensile Strength, min., psi.	Yield Point, min., psi.	Elongation in 2 in., min., per cent	Reduction of Area, min., per cent
	Over	Not Over				
N (Normalized, Quenched, and Tempered)		4	145 000	120 000	15	45
	4	7	140 000	115 000	14	40
	7	10	135 000	110 000	13	40
O (Normalized, Quenched, and Tempered)		4	170 000	140 000	13	40
	4	7	165 000	135 000	12	35
	7	10	160 000	130 000	11	35

Section 14.—Omit Paragraph (*c*) relating to crystalline fracture.

REVISIONS OF STANDARDS, IMMEDIATE ADOPTION

Standard Specifications for Carbon-Steel Bars for Springs (A 14 – 42):

The following revisions involve, primarily, check analyses of individual bars. To aid the purchaser in determining acceptability of bars or lots, amplification of the check analysis clause is recommended. It should be noted that these revisions do not change the present requirements on average chemical composition where several samples are checked.

Section 5.—Change from its present form to read as follows:

5. (*a*) An analysis may be made by the purchaser from finished bars representing each melt. The average of all the separate determinations made on the number of samples specified in Paragraph (*c*) shall fall within the limits prescribed in Section 3. Separate determinations may vary from the prescribed limits or ranges to the extent shown in Table I, but the several determinations of any element in a melt shall not vary both above and below this prescribed range.

(*b*) Samples for analysis shall be taken by machining off the entire cross-section of the bar; or by drilling parallel to the axis of round bars at any point midway between the center and surface; or by drilling through flat bars at a point midway between the edge and longitudinal axis.

(*c*) The minimum number of samples to be taken from material representing the same melt or lot, before rejection by the purchaser, shall be as follows:

	Minimum Number of Samples
Up to 5 tons, incl.	3
Over 5 to 10 tons, incl.	4
Over 10 to 15 tons, incl.	5
Over 15 tons	6

TABLE I.—PERMISSIBLE VARIATIONS OVER MAXIMUM OR UNDER MINIMUM LIMITS, PER CENT

Element	Cross-Sectional Area of Bars, sq. in.	
	0.75 and Under	Over 0.75
Carbon	...	0.01
Sulfur	0.005	0.008
Manganese	...	0.01

(*d*) Separate determinations shall be made on each sample and the results averaged, unless they clearly indicate mixed grades.

Standard Specifications for Carbon-Steel Bars for Springs, with Special Silicon Requirements (A 68 – 39):

Section 5.—Make the same changes in this section as recommended above in Specifications A 14 – 42, except that the permissible variations in chemical composition shall be as prescribed in Table II.

Standard Specifications for Welded and Seamless Steel Pipe (A 53 – 42):

To extend the scope of this widely used pipe specification to cover small electric-resistance-welded pipe, the following changes are recommended for immediate adoption. Manufacturers have indicated that there is a substantial tonnage of this material being produced and consequently a need for standardized requirements which can be met by the recommended changes:

Section 2 (*a*).—Change the first sentence to read as follows by the addition of the italicized words:

2. (*a*) The steel for both welded and seamless pipe shall be made by one or more of the following processes: open-hearth, electric-furnace, or acid-bessemer, *except that electric-resistance-welded pipe $\frac{1}{8}$ and $\frac{1}{4}$ in. in diameter shall be made from open-hearth steel.*

Section 2 (*b*).—Change the "3 in." diameter of pipe in lines 1 and 4 to read "4 in."

TABLE II.—PERMISSIBLE VARIATIONS OVER MAXIMUM OR UNDER MINIMUM LIMITS, PER CENT

Element	Cross-Sectional Area of Bars, sq. in.	
	0 75 and Under	Over 0.75
Carbon	0.02	0.03
Sulfur	0.005	0.008
Silicon	0.02	0.02
Manganese	...	0.01

Section 3.—Change the table to read as follows by the addition of the italicized words and figures:

	Lap-Welded	Seamless or Electric Resistance-Welded
Carbon, max., per cent	...	[a]
Phosphorus, max., per cent: Open-hearth or electric-furnace	0.06	0.045
Acid-bessemer	...	0.11

[a] *Electric-resistance-welded pipe $\frac{1}{8}$ and $\frac{1}{4}$ in. in diameter is obtainable in grade A quality only and the carbon content shall not exceed 0.10 per cent.*

Section 4.—At the end of this section on check analysis add the following sentence: "For electric-resistance-welded pipe $\frac{1}{8}$ and $\frac{1}{4}$ in. in diameter, the carbon content shall not exceed 0.12 per cent."

Table I.—In the column headed "Seamless or Electric-Resistance-Welded" insert footnote reference "*d*" after the word "Welded" and add the following as a footnote at the bottom of the table. "Tension tests shall not be required for electric-resistance-welded pipe $\frac{1}{8}$ and $\frac{1}{4}$ in. in diameter."

Table II.—In this table under the heading Size (Nominal Inside Diameter) include a listing for "$2\frac{1}{2}$ to 6 in., incl." butt-welded pipe with values of "1200" psi. for Standard Weight pipe, "1700" for Extra Strength Pipe; also with these values add a footnote reading as follows: "Butt-weld pipe is not made in sizes larger than 4 in. nominal."

Section 14.—In the first sentence of Paragraph (*a*) change "random lengths" to read "single random lengths"; also add the following as a new Paragraph (*c*): "(*c*) When standard weight or extra strong pipe is ordered in double random lengths, the minimum length shall be not less than 22 ft., with a minimum average for the order of 35 ft."

Section 17.—Revise the marking clause as recommended earlier in this Appendix.

Standard Specifications for Black and Hot-Dipped Zinc-Coated (Galvanized) Welded and Seamless Steel Pipe for Ordinary Uses (A 120 – 42):

Section 2 (b).—Make the same changes in this section as recommended above in Section 2 (*b*) of Specifications A 53.

Table I.—Make the same changes in this table as recommended above for Table II of Specifications A 53.

Section 12.—Make the same changes as recommended above in Section 14 of Specifications A 53.

Section 17.—Revise the marking clause as recommended earlier in this Appendix.

Standard Specifications for Low-Carbon Nickel-Steel Plates for Boilers and Other Pressure Vessels (A 203 – 42):

The revisions to these specifications (and also to Specifications A 204 which follows) modify the elongation values with which manufacturers have been having some trouble occasioned by the disproportionate decrease with the necking down of the specimen under tension test. As the gage length of the specimen increases, there is a marked decrease in the percentage of elongation of some alloy steels and up to the present time no relationship has been established. In the opinion of the subcommittee the change should not lower the quality of the material.

Section 7.—Reletter the present Paragraph (*b*) as (*c*) and insert a new Paragraph (*b*) to read as follows:

> (*b*) For plates $\frac{3}{8}$ to $\frac{3}{4}$ in., inclusive, in thickness, if the percentage of elongation of an 8-in-gage length test specimen falls not more than 3 per cent below the amount prescribed in Table II, the elongation shall be considered satisfactory provided the percentage of elongation in 2 in. across the break is not less than 30 per cent.
>
> NOTE.—A characteristic of certain types of alloy steels is a local disproportionate increase in the degree of necking down or contraction of the specimens under tension test; resulting in a decrease in the percentage of elongation as the gage length is increased. The effect is not so pronounced in the thicker plates.

Table II.—Change footnote "*a*" under this table to read as follows: "See Section 7 (*a*), (*b*), and (*c*)."

Section 14 (a).—Before the last sentence of this paragraph insert a new sentence to read as follows: "Plates, the maximum lengthwise and crosswise dimensions of which do not exceed 48 in., shall have the marking stamped in one place approximately midway between the center and an edge."

Standard Specifications for Molybdenum-Steel Plates for Boilers and Other Pressure Vessels (A 204 - 42):

Section 8.—Insert a new Paragraph (*b*) to read the same as recommended above in Section 7 of Specifications A 203, and reletter the present Paragraphs (*b*) and (*c*) accordingly.

Table II.—Change footnote "*a*" under this table to read as follows: "See Section 8 (*a*), (*b*), and (*d*)," and change footnote "*c*" to read "See Section 8 (*c*)."

Section 15 (*a*).—Make the same change in this section as recommended above in Section 14 (*a*) of Specifications A 203.

Standard Specifications for:

Boiler and Firebox Steel for Locomotives (A 30 - 42),

Carbon-Steel Plates for Stationary Boilers and Other Pressure Vessels (A 70 - 42),

Carbon-Silicon Plates of Ordinary Tensile Ranges for Fusion-Welded Boilers and Other Pressure Vessels (A 201 - 43),

Chrome-Manganese-Silicon (CMS) Alloy-Steel Plates for Boilers and Other Pressure Vessels (A 202 - 39),

High Tensile Strength Carbon-Silicon Steel Plates for Boiler and Other Pressure Vessels (Plates 4½ in. and Under in Thickness) (A 212 - 39):

In the section on "Marking" in each of these specifications insert a new sentence before the last sentence of Paragraph (*a*) to read the same as recommended above for Section 14 (*a*) of Specifications A 203.

The incorporation of these requirements on marking small plates will require the withdrawal of the Emergency Alternate Provisions for these specifications (except for EA - A 70 in which the provisions for sulfur content and tensile requirements will be retained), which actions will be taken by Committee E-10 Standards.

Standard Specifications for Alloy-Steel Bolting Material for High-Temperature Service (A 96 - 39):

Section 14.—Make the same changes in this section as recommended above in Section 12 of Specifications A 193.

Standard Specifications for Multiple-Wear Wrought Steel Wheels (A 57 - 39):

Section 9 (*d*).—Change to read as follows: "The tape size of wheels less than 44 in. in diameter shall not be less but may be 14 tapes more than specified. For wheels 44 in. and over in diameter the tape size shall not be less but may be 19 tapes more than specified."

Standard Specifications for Heat-Treated Wrought Steel Wheels (A 244 - 42):

Section 13 (*d*).—Make the same changes as recommended above in Section 9 (*d*) of Specifications A 57.

Standard Specifications for Electric-Resistance-Welded Steel Pipe (A 135 - 42):

Section 6.—Make the change involving modification in elongation as recommended in Table I; in addition change the basic minimum elongation in 2 in. from the present values of "30 and 25 per cent," min., respectively, for grades A and B to read "35 and 30 per cent," respectively.

Section 7.—Revise this section on flattening test as recommended earlier in this Appendix.

Standard Specifications for Forged or Rolled Alloy-Steel Pipe Flanges, Forged Fittings, and Valves and Parts for Service at Temperatures from 750 to 1100 F. (A 182 – 40):

Table I.—Change grade F 8 from its present form to read as shown in the accompanying Table III, and add three new grades, as shown.

TABLE III.

Grade	F 8	F 8m	F 8c	F 8t
Carbon, max., per cent	0.08	0.08	0.08	0.08
Manganese, max., per cent	2.50	2.50	2.50	2.50
Phosphorus, max., per cent	0.035	0.035	0.035	0.035
Sulfur, max., per cent	0.030	0.030	0.030	0.030
Silicon, max., per cent	0.85	0.85	0.85	0.85
Chromium, min., per cent	18.00	17.00	17.00	17.00
Nickel, min., per cent	8.00	10.00	9.50	9.00
Molybdenum, min., per cent	....	2.00	....	....
Titanium, per cent	....	....		[e]
Columbium, per cent	....	....	[d]	....

[d] Grade F 8c shall have a columbium content of not less than ten times the carbon content and not more than 1.00 per cent.

[e] Grade F 8t shall have a titanium content of not less than five times the carbon content and not more than 0.60 per cent.

Section 10.—Change from its present form to read as follows:

> 10. Valve bodies or fittings and other pressure-containing parts shall be tested after machining to the hydrostatic pressure prescribed in the table below, and shall show no leaks. No hydrostatic test is required for welding neck or other flanges.

Primary Service Pressure Rating at 900 F., psi	Standard Hydrostatic Test Pressure, psi.
300	900
400	1200
600	1800
900	2400
1500	4200
2500	7200

Standard Specifications for Seamless Alloy-Steel Boiler and Superheater Tubes (A 213 – 42):

Sections 6 and 7.—Revise the requirements for modifications in elongation and the section on flattening test as recommended earlier in this Appendix.

Section 19 (a).—Revise this section on marking as recommended earlier in this Appendix.

Table II.—Revise the requirements for grades T 8, T 18, T 19, and T 20 as shown in the accompanying Table IV.

TABLE IV.

Grade	T 8 or P 8	T 18	T 19	T 20	T 24
Carbon, max., per cent	0.08	0.08	0.08	0.08	0.08
Manganese, max., per cent	2.00	2.00	2.00	2.00	2.00
Phosphorus, max., per cent	0.03	0.03	0.03	0.03	0.03
Sulfur, max., per cent	0.03	0.03	0.03	0.03	0.03
Silicon, max., per cent	0.75	0.75	0.75	0.75	0.75
Nickel, per cent	8.00 to 11.00	9.00 to 13.00	9.00 to 13.00	11.00 to 14.00	11.00 to 14.00
Chromium, per cent	18.00 to 20.00	17.00 to 20.00	17.00 to 20.00	16.00 to 18.00	18.00 to 20.00
Molybdenum, per cent	....		....	2.00 to 3.00	3.00 to 4.00
Titanium	....	[b]	....	....	....
Columbium	....	....	[c]	....	....

[b] Grade T 18 shall have a titanium content of not less than five times the carbon content and not more than 0.60 per cent.

[c] Grade T 19 shall have a columbium content of not less than ten times the carbon content and not more than 1.00 per cent.

Standard Specifications for Atomic-Hydrogen-Arc Welded and Electric-Resistance-Welded Alloy-Steel Boiler and Superheater Tubes (A 249 – 42):

Table I.—Change the requirements as to chemical composition to read as shown in the accompanying Table IV.

Section 19 (a).—Revise this section on marking as recommended earlier in this Appendix.

Standard Specifications for Factory-Made Wrought Carbon-Steel and Carbon-Molybdenum-Steel Welding Fittings (A 234 - 42):

Section 3 (a).—Delete the words "forge welding" which appear in the first sentence.

Section 6 (d).—Delete the present Paragraph (*d*) and reletter the subsequent paragraphs accordingly.

ADOPTION OF TENTATIVE STANDARDS AS STANDARD

Tentative Specifications for Manganese-Vanadium Steel Plates for Boilers and Other Pressure Vessels (A 225 - 39 T):

The committee recommends that these specifications, revised as follows, be approved for reference to letter ballot of the Society for adoption as standard:

Section 7.—Insert a new Paragraph (*d*) to read the same as recommended above for Section 7 of Specifications A 203, and reletter the present Paragraphs (*d*), (*e*), and (*f*) accordingly.

Under the table in this section change footnote "*a*" to read: "See Paragraphs (*c*), (*d*), and (*f*)," and change footnote "*c*" to read "See Paragraph (*e*)."

Section 14 (a).—Before the last sentence of this paragraph insert a new sentence to read as follows: "Plates, the maximum lengthwise and crosswise dimensions of which do not exceed 48 in., shall have the marking stamped in one place approximately midway between the center and an edge."

Tentative Specifications for Welded and Seamless Steel Pipe Piles (A 252 - 42 T):

Section 9 (a).—Change from its present form to read as follows:

> 9. (*a*) Unless otherwise agreed upon between the manufacturer and the purchaser, material shall be ordered in single or double lengths, and shall be furnished in accordance with the following regular practice:
>
> Single random lengths....16 to 25 ft., incl.
> Double random lengths
> over 25 ft. with a minimum average of 35 ft.

Section 10.—Change the last sentence of this section by the addition of the italicized words and figures: "Plain end material for welding, unless otherwise specified, shall be beveled to an angle of 30 deg., *with a tolerance of plus 5 deg., minus 0 deg.*, with a width of flat at the end of the pipe $\frac{1}{16} \pm \frac{1}{32}$ in."

Tentative Specifications for Welded Alloyed Open-Hearth Iron Pipe (A 253 - 42 T):

In order that standards covering certain larger sizes of butt-welded pipe now being manufactured shall be recognized, the following modifications are proposed:

Section 2 (b).—Change the second sentence to read "Pipe from 2 in. to 4 in. inclusive in nominal diameter may be either furnace-butt-welded or electric-resistance-welded." Change the "3 in." diameter of pipe in the last sentence to read "4 in."

Table I.—Make the same changes in this table as recommended above in Table II of Specifications A 53.

WITHDRAWAL OF STANDARDS

Standard Specifications for Carbon-Steel and Alloy-Steel Blooms, Billets, and Slabs for Forgings (A 17 - 29):

At the time the Tentative Specifications for Carbon-Steel and Alloy-Steel Blooms, Billets, and Slabs for Forgings (A 248 - 41 T) were issued in 1941, it was suggested that Specifications A 17 - 29 be withdrawn simultaneously but use in export trade and in certain domestic fields led to the retention of this standard which ultimately, however, was to be replaced by A 248. It is now proposed to withdraw Standard A 17, since Specifications A 248 have approximately three years standing and since it may also be superseded as the Section on Materials for Forgings perfects its proposed new specifications for carbon-steel and on alloy-steel forgings (see discussion on forgings earlier in this report).

Standard Specifications for Forge-Welded Steel Pipe (A 136 – 34):

There being no evidence of further use of these specifications, they are recommended for withdrawal.

Standard Specifications for Riveted Steel and Wrought-Iron Pipe (A 138 – 34):

These specifications are under the jurisdiction of Committee A-1 and of Committee A-2 on Wrought Iron. Committee A-1 recommends their withdrawal and has so notified Committee A-2.

REPORT OF COMMITTEE A-2
ON
WROUGHT IRON

While Committee A-2 on Wrought Iron has held no meeting during the past year, the committee has furthered some of its activities by correspondence as indicated in this report.

The membership of the committee now totals 47, of whom 15 are classified as producers, 26 as consumers, and 6 as general interest members.

I. Revision of Standard, Immediate Adoption

Committee A-2, as joint sponsor, concurs in the recommendation of Committee A-1 on Steel that the requirement for marking the hydrostatic test pressure on pipe be deleted from the Standard Specifications for Lap-Welded and Seamless Steel and Lap-Welded Iron Boiler Tubes (A 83 – 42) and that it be indicated that the required marking shall include the symbol "A.S.T.M. A 83."

II. Withdrawal of Standard

The committee also concurs in the recommendation of Committee A-1 that the Standard Specifications for Riveted Steel and Wrought Iron Pipe (A 138 – 34) be withdrawn since this type of pipe is no longer manufactured.

III. Reaffirmation of Standards

The following standards, which have been in effect for six or more years without revision, have been reviewed and reaffirmed by the committee by letter ballot vote since they are considered to be in agreement with current practice.

Standard Specifications for:

Refined Iron Bars (A 41 – 36),
Common Iron Bars (A 85 – 36), and

Standard Definitions of:

Terms Relating to Wrought Iron (A 81 – 33).

In the light of experience, Committee A-2 is planning to submit to Committee E-10 on Standards a proposed tentative revision of the Standard Specifications for Wrought Iron Plates (A 42 – 39) which will provide for decreasing the yield point–tensile strength ratios with increasing thickness of plate. This revision consists of a new sentence to be added at the end of Section 5 (*f*) reading as follows: "For material over ¾ in. in thickness, the minimum yield point shall not be less than one half the tensile strength." When the specifications were adopted in 1939, little or no plate was being produced in excess of ¾ in. in thickness. More recently with the production of heavier gage plate, it has been found impossible to meet the minimum yield point of 27,000 psi. and the additional sentence covering yield point requirement is made necessary by that situation.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, C. B. Bryant.
Vice-Chairman, D. M. Stembel.
Secretary, James Aston.

This report has been submitted to letter ballot of the committee which consists of 47 members; 43 members have returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

C. B. BRYANT,
Chairman.

W. C. MASTERS,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee A-2 presented to the Society through Committee E-10 on Standards the proposed tentative revision of the Standard Specifications for Wrought Iron Plates (A 42 – 39), referred to in the report. This recommendation was accepted by Committee E-10 on August 28, 1944, and the tentative revision appears in the 1944 Book of A.S.T.M. Standards, Part I, p. 2002.

REPORT OF COMMITTEE A-3

ON

CAST IRON

Since the 1943 Annual Meeting of the Society, Committee A-3 on Cast Iron has held one meeting in Cincinnati, Ohio, on February 29, 1944. Another meeting will be held in June during this Annual Meeting of the Society.

During the year 18 new members have been elected, and 1 resignation accepted. Two members have been lost through death, Enrique Touceda and T. I. Curtin. The total membership of the committee is now 132, of whom 43 are classified as producers, 56 as consumers, and 33 as general interest members. In addition, there are 5 consulting members.

The following resolution has been adopted by the committee:

> RESOLVED: That in the death of Enrique Touceda, Committee A-3 loses a member of outstanding reputation and ability in the field of ferrous castings. Mr. Touceda, Director of Touceda Chemical and Physical Laboratories, Albany, N. Y., was a long-time member of the Society and a member of Committee A-3 on Cast Iron since its organization in 1903. This committee pays tribute to this long association and regrets the loss of his services.

During the year each subcommittee has reviewed the specifications under its jurisdiction. This review indicated that the A-3 specifications are functioning satisfactorily and do not require revision at this time. However, it has been proposed that the emergency alternate provisions in the Standard Specifications for Lightweight and Thin-Sectioned Gray Iron Castings (A 190 – 40) be incorporated in the standard. This matter will be presented for discussion and vote at the June meeting, subject to later confirmation by letter ballot.

Pursuant to the instructions of Committee A-3, the chairman appointed a nominating committee, comprising V. A. Crosby, T. E. Eagan, and J. S. Vanick. This committee proposed the following nominees:

Chairman, James T. MacKenzie.
Vice-Chairman, Edward R. Young.
Secretary, Charles O. Burgess.

The above officers were elected for the ensuing term of two years.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Pig Iron (H. W. Stuart, chairman).—This group has been reorganized under the chairmanship of H. W. Stuart. Its membership now consists of eight producers of pig iron, eight consumers, and one general interest member. Two meetings have been held and distinct progress has been made in the preparation of a thorough revision of the Standard Specifications for Foundry Pig Iron (A 43 – 24).

Subcommittee VI on General Castings (Hyman Bornstein, chairman).—The subcommittee has reviewed and reaffirmed the Standard Specifications for Gray Iron Castings (A 48 – 41). Further study is to be made of the requirements for the optional transverse test and the possibility of giving some guide as to Brinell hardness for the various classes of gray iron castings.

Subcommittee VII on Microstructure of Cast Iron (G. F. Comstock, chairman).—

An addition to the preferred methods of polishing in the Tentative Recommended Practice for Evaluating the Microstructure of Graphite in Gray Iron (A 247 – 41 T) is under consideration. In the meantime, it is recommended that this recommended practice be continued as tentative.

Subcommittee X on Nomenclature and Definitions (A. J. Herzig, chairman).—No change in the Tentative Definitions of Terms Relating to Cast Iron (A 196 – 42 T) is recommended at this time.

Subcommittee XI on Methods of Testing (V. A. Crosby, chairman), *Subcommittee XV on Impact Testing* (J. T. MacKenzie, chairman), and *Subcommittee XVI on Heat Treatment of Cast Iron* (J. S. Vanick, chairman).—The research programs of these three subcommittees have been held in abeyance because of the difficulties encountered in the procurement of equipment and because of lack of time to pursue these long-range studies during this war period.

Subcommittee XVII on Gray Iron Castings for Valves, Flanges and Pipe Fittings (J. J. Kanter, chairman).—No revision is recommended in the Standard Specifications for Gray Iron Castings for Valves, Flanges, and Pipe Fittings (A 126 – 42).

Subcommittee XXI on Pressure Pipe (T. H. Wiggin, chairman).—This subcommittee is developing specifications for centrifugal pipe.

Subcommittee XXII on Elevated Temperature Properties of Cast Iron (J. S. Vanick, chairman).—Proposed tentative specifications for cast iron for use in pressure parts, within the temperature ranges of 450 to 650 F. are in preparation by the subcommittee.[1]

This report has been submitted to letter ballot of the committee, which consists of 132 members; 98 members returned their ballots, of whom 97 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the committee,

J. W. BOLTON,
Chairman.
J. T. MACKENZIE,
Vice-Chairman.

E. R. YOUNG,
Secretary.

---

[1] See Editorial Note below.

EDITORIAL NOTE

Subsequent to the Annual Meeting Committee A-3 presented to the Society through Committee E-10 on Standards the following recommendations:

Tentative Specifications for:

Lightweight and Thin-Sectioned Gray Iron Castings (A 190 – 44 T), to replace Standard Specifications A 190 – 40 and Emergency Alternate Provisions EA – A 190,

Automotive Gray Iron Castings (A 159 – 44 T), as a tentative revision of Standard Specifications A 159 – 41, and

Gray Iron Castings for Pressure-Containing Parts for Temperatures up to 650 F. (A 278 – 44 T).

The first recommendation was accepted by Committee E-10 on August 28, 1944, the other two recommendations having been accepted on November 22, 1944. The tentative specifications appear in the 1944 Book of A.S.T.M. Standards, Part I.

REPORT OF COMMITTEE A-5
ON
CORROSION OF IRON AND STEEL

Committee A-5 on the Corrosion of Iron and Steel held two meetings during the year: one on June 29, 1943, in Pittsburgh, Pa., during the Annual Meeting of the Society, and the other on March 1, 1944, in Cincinnati, Ohio, during the Spring Group Meetings of the Society.

Since the last report 7 new members have been elected and 5 members resigned; the total membership of the committee is now 132, of whom 60 are classified as producers, 44 as consumers, and 28 as general interest members.

EMERGENCY ALTERNATE PROVISIONS

The committee is recommending to Committee E-10 on Standards the withdrawal of the Emergency Alternate Provisions in two specifications as noted below which were accepted by the Standards Committee on January 28, 1944:

Standard Specifications for:

Zinc-Coated (Galvanized) Iron or Steel Farm-Field and Railroad Right-of-Way Wire Fencing (EA-A 116), and

Zinc-Coated (Galvanized) Iron or Steel Barbed Wire (EA-A 121).

When these two emergency provisions were being developed, half or less of the designs of fencing and barbed wire defined in the standard specifications were available under War Production Board Limitation Order L-211. Likewise, the same limitation order prevented fabrication of the products with several of the gages of heavier wire and with the heavy and medium zinc coating weights described in the standard specifications. Within a few weeks after the two sets of provisions were issued, Limitation Order L-211 was modified to remove certain restrictions on fencing so that there is no longer a need for either of the Emergency Alternate Provisions.[1]

WITHDRAWAL OF EMERGENCY SPECIFICATIONS AND REPLACEMENT BY NEW TENTATIVE STANDARD

The committee recommends for publication as tentative revised Specifications for Lead Coating (Hot-Dip) on Iron or Steel Hardware,[2] to replace the Emergency Specifications for Lead Coating (Hot-Dip) on Iron or Steel Hardware (ES - 2).[1]

STATUS OF STANDARDS AND TENTATIVE STANDARDS BEING REPUBLISHED WITHOUT CHANGE

The standards listed below are recommended for publication without change. The first five of these have been approved as American Standard by the American Standards Association since the last report and the A.S.A. numbers are indicated:

Standard Specifications for:

Zinc-Coated (Galvanized) Iron or Steel Farm-Field and Railroad Right-of-Way Wire Fencing (A 116–39; ASA G8.9–1944),

Zinc-Coated (Galvanized) Iron or Steel Barbed Wire (A 121 - 39; G8.10–1944),

Zinc-Coated Steel Wire Strand ("Galvanized" and Class A) ("Extra Galvanized") (A 122 - 41; G8.6–1943),

Zinc-Coated Steel Wire Strand (Class B and Class C Coatings) (A 218 - 41; G8.11–1944),

Zinc-Coated (Galvanized) Iron or Steel Telephone and Telegraph Line Wire (A 111 - 43; G8.3–1944),

---

[1] See Editorial Note, p. 91.

[2] These specifications were accepted as tentative by the Society and appear in the 1944 Book of A.S.T.M. Standards, Part I, p. 1396.

Zinc-Coated (Galvanized) Iron or Steel Tie Wires (A 112 - 33; G8.4-1935),
Zinc-Coated Iron or Steel Chain-Link Fence Fabric, Galvanized After Weaving (A 117 - 33; G8.5-1935),
Zinc-Coated (Galvanized) Iron or Steel Sheets (A 93 - 27; G8b1-1931),
Zinc (Hot-Galvanized) Coatings on Structural Steel Shapes, Plates, Bars, and Their Products (A 123 - 33; G8.1-1933),

Standard Methods of:

Test for Weight of Coating on Zinc-Coated (Galvanized) Iron or Steel Articles (A 90 - 39),
Test for Uniformity of Coating by the Preece Test (Copper Sulfate Dip) on Zinc-Coated (Galvanized) Iron or Steel Articles (A 239 - 41), and

Standard Recommended Practice for:

Safeguarding Against Embrittlement of Hot Galvanized Structural Steel Products and Procedure for Detecting Embrittlement (A 143 - 35).

It is recommended that the following tentative standards be continued as tentative without change:

Tentative Specifications for:

Zinc-Coated (Galvanized) Iron or Steel Sheets (A 93 - 38 T),
Zinc Coating (Hot-Dip) on Iron and Steel Hardware (A 153 - 42T),
Electrodeposited Coatings of Cadmium on Steel (A 165 - 40 T),
Electrodeposited Coatings of Zinc on Steel (A 164 - 40 T), and
Tentative Methods of Test for Local Thickness of Electrodeposited Coatings (A 219 - 40 T).

It is not likely that Specifications A117 will undergo any revision until the resumption of activity in chain link fence fabrication after the war.

Standard and Tentative Specifications A93, both dealing with galvanized sheets, require revision, but such action scarcely seems feasible until the end of the war period.

Specifications A165, A164, and Methods A219, dealing with electrodeposited coatings are believed to be in need of revision before they are recommended for adoption as standard, but the necessary investigational work can probably not be completed until after the war.

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 132 members, with the results shown in Table I.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. WITHDRAWAL OF EMERGENCY ALTERNATE PROVISIONS STANDARDS			
Provisions in Spec. for Iron or Steel Farm Field and Railroad Right-of-Way Wire Fencing (A 116 - 39)	57	0	36
Provisions in Spec. for Zinc-Coated (Galvanized) Iron or Steel Barbed Wire (A 121 - 39)	59	0	34
II. WITHDRAWAL OF EMERGENCY SPECIFICATION			
Emergency Spec. for Lead Coating (Hot-Dip) on Iron or Steel Hardware (ES-2)	62	0	31
III. NEW TENTATIVE STANDARD			
Spec. for Lead Coating (Hot-Dip) on Iron or Steel Hardware	57	0	36
IV. TENTATIVE STANDARDS CONTINUED AS TENTATIVE WITHOUT CHANGE			
Spec. for Zinc-Coated (Galvanized) Iron or Steel Sheets (A 93 - 38 T)	73	0	20
Spec. for Zinc-Coating (Hot-Dip) on Iron and Steel Hardware (A 153 - 42 T)	67	0	26
Spec. for Electrodeposited Coatings of Cadmium on Steel (A 165 - 40 T)	63	1	29
Spec. for Electrodeposited Coatings of Zinc on Steel (A 164 - 40 T)	66	1	26
Test for Local Thickness of Electrodeposited Coatings (A 219 - 40 T)	64	1	28

ACTIVITIES OF SUBCOMMITTEES

Subcommittee III on Inspection of Annapolis Tests (Ewart S. Taylerson, chairman).—The specimens of copper-bearing and non-copper-bearing corrugated black sheets that have been exposed at Annapolis, Md., since October 17, 1916, were inspected on April

TABLE II.—RECORD OF FAILURES AT ANNAPOLIS OF 22 GAGE COPPER-BEARING AND NON-COPPER-BEARING CORRUGATED BLACK SHEETS.
Sheets Exposed October 17, 1916. Inspections Made Semiannually from 1917 to 1944.

Group	Designation	Series	Average Analysis, per cent						Number of Sheets in Test[a]	Life of Each Failed Sheet, yr.																Number of Sheets in Test	Number of Sheets Failed	Average Life of Sheets, yr.	Group
			Carbon	Manganese	Phosphorus	Sulfur	Silicon	Copper																					
Z.....	Open-hearth Steel	B	0.032	0.32	0.063	0.042	..	0.019	3	13.5	17.0	19.0	..	..	..	..	..	..	..	..	..	..	..	..	..	3	3	16.5	....Z
O.....	Open-hearth Steel	A	0.121	0.536	0.008	0.030	0.249	0.020	12	7.0	9.0	9.0	9.0	9.0	9.5	10.0	10.0	11.0	11.0	13.0	17.0	..	..	..	..	12	12	10.4	....O
B....	Open-hearth Steel	A	0.09	0.38	0.017	0.062	0.036	0.084	3	20.0	20.5	24.0	..	..	..	..	..	..	..	..	..	..	..	..	..	3	3	21.5	....B
M....	Open-hearth Steel	B	0.093	0.419	0.013	0.041	0.011	0.185	13	20.0	20.5	23.5	23.5	23.5	24.0	24.0	24.0	24.0	24.0	24.0	24.0	25.0	..	..	..	13	13	23.4	....M
B.....	Open-hearth Steel	A	0.06	0.27	0.014	0.053	0.006	0.187	9	19.5	20.0	21.5	22.0	22.5	23.0	26.0	*	*	..	..	..	..	..	..	..	9	7	..	....B
Z.....	Open-hearth Steel	B	0.067	0.351	0.045	0.052	0.003	0.187	3	27.0	*	*	..	..	..	..	..	..	..	..	..	..	..	..	..	3	1	..	....Z
T.....	Open-hearth Steel	B	0.083	0.313	0.009	0.020	0.005	0.227	14	19.5	19.5	19.5	21.5	21.5	21.5	23.0	23.5	23.5	23.5	24.0	24.0	24.0	24.0	..	..	14	14	22.3	....T
K.....	Open-hearth Steel (Acid)	A	0.107	0.447	0.091	0.046	0.004	0.237	14	24.5	*	*	*	*	*	*	*	*	*	*	*	*	*	..	..	14	1	..	....K
H.....	Open-hearth Steel	A	0.069	0.387	0.016	0.027	0.004	0.244	10	19.5	21.0	21.5	23.0	23.5	23.5	23.5	24.0	24.0	25.0	..	..	..	..	..	..	10	10	22.9	....H
Z.....	Open-hearth Steel	B	0.065	0.35	0.050	0.059	0.003	0.264	2	24.5	*	..	..	..	..	..	..	..	..	..	..	..	..	..	..	2	1	..	....Z
Z.....	Open-hearth Steel	B	0.073	0.42	0.052	0.054	Trace	0.641	3	*	*	*	..	..	..	..	..	..	..	..	..	..	..	..	..	3	0	..	....Z
S......	Open-hearth Iron	B	0.02	0.023	0.006	0.022	0.004	0.022	14	7.0	8.0	8.5	9.0	9.5	10.0	11.0	11.5	11.5	12.5	12.5	12.5	12.5	12.5	..	..	14	14	10.6	.....S
D.....	Open-hearth Iron	A	0.02	0.026	0.004	0.022	0.002	0.024	6	16.0	16.0	16.0	19.5	19.5	23.5	..	..	..	..	..	..	..	..	..	..	6	6	18.4	....D
X.....	Open-hearth Iron	B	0.021	0.055	0.007	0.031	0.004	0.027	14	10.5	13.0	13.5	14.5	14.5	16.0	16.0	16.5	16.5	17.0	17.5	17.5	18.0	19.0	..	..	14	14	15.7	X
C.....	Open-hearth Iron	A	0.01	0.028	0.002	0.027	0.002	0.141	3	17.5	20.5	23.5	..	..	..	..	..	..	..	..	..	..	..	..	..	3	3	20.5	C
C.....	Open-hearth Iron	A	0.015	0.028	0.006	0.036	0.003	0.194	9	16.5	16.5	18.5	19.0	19.0	20.0	20.5	21.5	21.5	..	..	..	..	..	..	..	9	9	19.2	C
U.....	Open-hearth Iron	B	0.017	0.074	0.008	0.037	0.005	0.260	13	15.5	16.5	19.0	19.0	19.0	19.0	19.0	19.5	20.0	20.0	21.0	21.0	22.5	..	..	..	13	13	19.3	....U
V.....	Open-hearth Iron	B	0.018	0.051	0.007	0.021	0.005	0.304	14	17.0	17.0	17.5	18.5	18.5	19.0	20.0	20.0	20.5	21.0	22.0	22.0	22.5	24.0	..	..	14	14	20.0	V
A.....	Bessemer Steel	A	0.038	0.386	0.089	0.040	0.007	0.014	15	15.5	16.5	16.5	17.0	17.0	17.0	18.0	19.0	19.0	19.5	19.5	19.5	19.5	19.5	20.0	..	15	15	18.2	....A
Z......	Bessemer Steel	B	0.063	0.41	0.102	0.044	0.009	0.013	3	11.5	11.5	11.5	..	..	..	..	..	..	..	..	..	..	..	..	..	3	3	11.5	....Z
Z.....	Bessemer Steel	B	0.077	0.44	0.095	0.036	0.003	0.140	3	*	*	*	..	..	..	..	..	..	..	..	..	..	..	..	..	3	0	..	....Z
I......	Bessemer Steel	A	0.041	0.365	0.097	0.068	0.008	0.252	15	24.0	26.0	26.5	26.5	26.5	26.5	27.0	*	*	*	*	*	*	*	*	..	15	7	..	I
Z.....	Bessemer Steel	B	0.058	0.37	0.093	0.043	0.009	0.269	3	*	*	*	..	..	..	..	..	..	..	..	..	..	..	..	..	3	0	..	....Z
Z.....	Bessemer Steel	B	0.055	0.38	0.110	0.046	..	0.527	3	*	*	*	..	..	..	..	..	..	..	..	..	..	..	..	..	3	0	..	....Z
Y.....	Wrought Iron	B	0.03	0.055	0.139	0.021	0.218	0.020	3	18.0	19.5	23.5	..	..	..	..	..	..	..	..	..	..	..	..	..	3	3	20.3	....Y
E.....	Wrought Iron	A	0.033	0.034	0.114	0.021	0.134	0.283	10	19.5	20.5	21.0	21.0	23.0	23.0	23.0	23.0	24.0	25.0	..	..	..	..	..	..	10	10	22.3	....E
							Total.......		214															Total....		214	176		

* Indicates unfailed sheet.

[a] The number of sheets in the test indicated in this table is less than the number shown in earlier reports because certain sheets were discarded due to mechanical damage.

27, and October 15, 1943. Four failures among the No. 22 gage sheets were found during the April inspection (I-5, 11, 13 and 15), and two in October, (I-12 and Z-504). No failures of No. 16 gage material were noted this year. A summary of the failures to date is given in Table II.

Subcommittee V on Total Immersion Tests (W. J. Jeffries, chairman).—The test program of this subcommittee on underwater exposure tests have been completed. The preparation of a final report involves a statistical study of a large amount of accumulated data which the committee has not yet been able to complete because of wartime activities.

Subcommittee VI on Specifications for Metallic-Coated Products (T. R. Galloway, chairman).—Substantially all the information presented earlier in this report with respect to the status of standards and tentative standards is the result of the activities of this subcommittee.

Additional work under consideration by Subcommittee VI includes revision of the weight of certain coating requirements incorporated in the Tentative Specifications for Zinc Coating (Hot-Dip) on Iron and Steel Hardware (A 153 - 42 T). The completion of this work ties in with the development by Subcommittee VII of an improved method of determining the weight of zinc coatings on malleable iron castings.

This committee is starting work on the development of specifications for long terne sheets.

Following the 1943 Annual Meeting, Subcommittee VI undertook the preparation of specifications for lead-alloy-coated sheets looking toward their publication as an emergency standard. By the time the proposed specifications were prepared, conditions had changed so that publication under the emergency procedure did not seem justified. Presentation for publication as tentative was considered, but it now appears that further work is desirable before this step is taken. The draft already prepared was based on the practice of a single supplier—the only information available to the committee. Recently a new manufacturer has entered the field, and it is believed that the new practices should be taken into account before submission of lead-coated sheet specifications for publication as tentative. The draft already prepared is published in the Appendix as information only and for the purposes of developing comments as a guide to further action.

Subcommittee VII on Methods of Testing (R. W. Baker, chairman).—A section of this subcommittee is actively working on the evaluation of tests which are now employed, or are proposed, for field use (dropping tests, magnetic tests, and the like) in inspecting specimens to determine the weights or thicknesses of protective coatings which have been applied. There have been delays caused by the inavailability of magnetic equipment.

This subcommittee also has in hand the development of an improved method for determining the weight of zinc coatings on malleable iron castings since the standard stripping test (Specifications A 153) is not fully satisfactory when applied to this class of product.

The Methods of Test for Local Thickness of Electrodeposited Coatings (A 219 - 40 T), which are under the jurisdiction of Subcommittee VII, are recommended for continuation as tentative without revision.

Subcommittee VIII on Field Tests of Metallic Coatings (C. E. Reinhard, chairman).—Since the last report, R. F. Passano has resigned as chairman of this subcommittee and the present chairman appointed. Also, D. J. McKinnon has been appointed chairman of the Hardware Inspection Section of this subcommittee, replacing W. L. Maucher, resigned.

Subcommittee VIII has carried on the regular inspection of its large collection of galvanized sheet specimens, metallic-coated hardware parts, and wire and wire products which are undergoing atmospheric exposure tests.

This annual report follows the usual precedent of Committee A-5 in choosing to publish detailed inspection records of sheet and hardware specimens only in even numbered years (as 1944) and to delay one year (until 1945) the printing of detailed records on the performance of wire, fencing, and strand products.

The inspection findings on galvanized sheets and metallic-coated hardware together with certain interpretations of these findings are presented in the more detailed report appended hereto. This current report is expected to be the last requiring extensive tabulations of hardware inspection results. The hardware tests at Brunot Island (Pittsburgh), Pa., and at Altoona, Pa., have been discontinued, and the test racks at Sandy Hook, N. J., and State College, Pa., have been reconditioned so as to retain only about one fourth of the specimens for future observation.

The following officers of Committee A-5 have been elected for the ensuing term of two years:

Chairman, C. D. Hocker.
First Vice-Chairman, R. F. Passano.
Second Vice-Chairman, T. R. Galloway.

This report has been submitted to letter ballot of the committee, which consists of 132 members; 97 members returned their ballots, of whom 96 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the committee,

C. D. Hocker,
Chairman.

J. B. Dixon,
Secretary.

Editorial Note

Subsequent to the Annual Meeting Committee A-5 recommended to Committee E-10 on Standards that the following emergency specifications and provisions be withdrawn:

Emergency Specifications for:

Lead Coating (Hot-Dip) on Iron or Steel Hardware (ES - 2),

Emergency Alternate Provisions in:

Standard Specifications for Zinc-Coated (Galvanized) Iron or Steel Farm-Field and Railroad Right-of-Way Wire Fencing (EA - A 116), and
Standard Specifications for Zinc-Coated (Galvanized) Iron or Steel Barbed Wire (EA - A 121)

This recommendation was accepted by Committee E-10 on August 28, 1944.

REPORT OF SUBCOMMITTEE VIII ON FIELD TESTS OF METALLIC COATINGS

GALVANIZED SHEET EXPOSURE TESTS

During the past two years, semiannual inspections of exposed galvanized sheets have been made in April and October at Altoona, Pa.; Brunot Island (Pittsburgh), Pa.; Sandy Hook, N. J.; and State College, Pa. One inspection only was made at Key West, Fla.—in April, 1944.

The inspections in 1942 and 1943 at Altoona and Brunot Island, where all coatings had previously failed, have shown an increasing number of perforations of sheets which had originally been coated. The inspections at Sandy Hook and State College show additional sheets starting to rust, but no perforations yet appearing in sheets originally coated. The Key West specimens show additional failures of the type characteristic of this location which are described later.

This report shows the record of new zinc coating failures and of new perforations occurring in the past two years. The information is presented in five tables (one for each site) which also include certain summaries of specimen performances. Also the report includes a graphic presentation of sheet performances at Altoona and Brunot Island where the tests are approaching a definitive stage.

Figure 1 shows the life of zinc coatings on iron and steel sheets at Altoona, Pa., and Brunot Island, Pa. The figure indicates the progressive development of rust with time. These curves are a reproduction and extension of some of those published in the 1935 report.[1] The areas plotted as ordinates in Fig. 1 were calculated by averaging the rusted areas of all sheets in each class at a given time. These data differ slightly from those shown in Tables I and II which were derived by averaging the time for all sheets in each class to reach a given condition.

The tabulated information shown in the report is noted below in the paragraphs relating to each of the locations.

Altoona, Pa. (*Last tabulated report in 1934*):

A summary of the coated sheet failures (perforations) has been assembled in Table I. Included are data on (1) the average time of exposure for each weight of coating class until first appearance of rust and until complete removal of the coating (100 per cent of surface area rusted) and (2) the average, minimum, and maximum life of uncoated sheets. These data, while incomplete, furnish some preliminary evidence of the extent to which the galvanized coatings contributed to the total life of the sheets at this location.

Status.—(1) Complete removal of coating has occurred for all specimens (100 per cent of surface areas rusted). (2) All uncoated sheets have failed by perforation. (3) Perforation of originally coated sheets has taken place among the specimens of every weight of coating class, although largely confined to classes including and below the 1.50-oz. (4) Three sheets were lost due to storm before perforation had occurred.

---

[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 35, p. 89 (1935).

remaining uncoated sheet was found to be perforated at the October, 1942, inspection after an exposure of 16.5 yr.

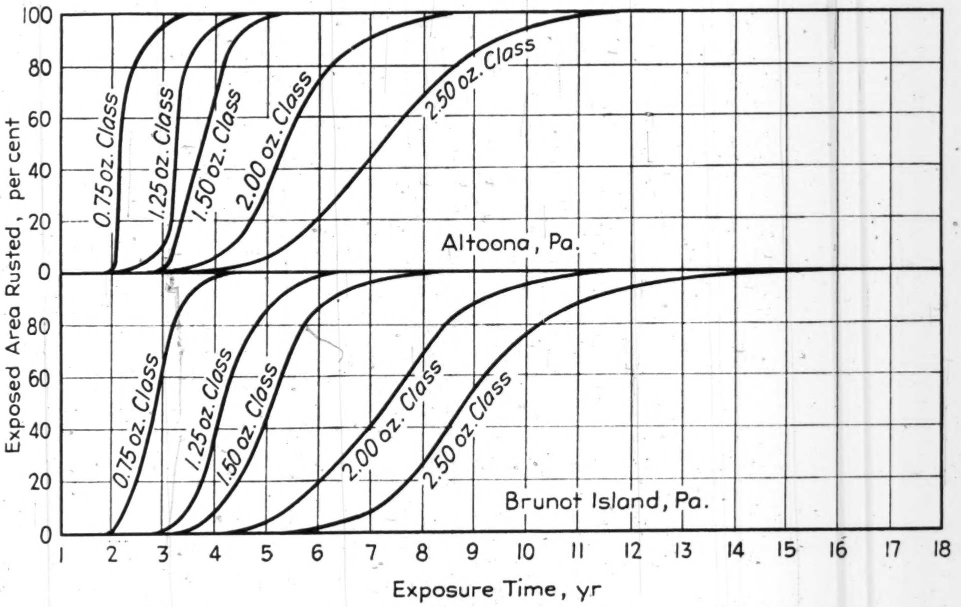


FIG. 1.—Life of Zinc Coatings on Iron and Steel Indicating the Progressive Development of Rust.

TABLE I.—SUMMARY OF SHEET FAILURES ON ALTOONA, PA., TEST RACK[a].

Sheets Exposed April 22, 1926.

Description	Number of Specimens in Test	Average Life of Coating to First Rust, yr.	Average Time to Complete Removal of Coating, yr.	Time to First Perforation, yr.			Total Number of Sheets Failed Oct. 12, 1943, 17.47 yr.
				Average	Minimum	Maximum	
No. 16 gage, 2.50 oz. per sq. ft.	10	4.4	11.1	...	16.5	...	2
No. 22 gage, 2.50 oz. per sq. ft.	18	4.6	11.2	...	15.5	...	3
No. 22 gage, 2.00 oz. per sq. ft.	18	3.8	8.1	...	16.5	...	3
No. 22 gage, 1.50 oz. per sq. ft.	18	3.0	5.7	(16.0)[b]	14.5	...	10
No. 22 gage, 1.25 oz. per sq. ft	18	2.4	4.3	(15.9)[b]	13.5	...	12(1)[c]
No. 22 gage, 0.75 oz. per sq. ft.	14	1.9	3.1	(13.2)[b]	4.3(8.5)[d]	...	11(1)[c]
No. 28 gage, 0.75 oz. per sq. ft.	10	2.1	3.1	9.6	7.1	11.0	10(1)[c]
No. 22 gage, uncoated	10	...	...	6.5	2.0	13.5	10(1)[c]

[a] A detailed record of failures of coating may be found in Table I of the 1933 Report; see *Proceedings*, Am. Soc. Testing Mats., Vol. 33, p. 150 (1933).

[b] Figures shown in parentheses are not to be considered final as not all specimens in this weight of coating class have failed.

[c] Number of sheets blown away by storm which had not previously been marked as perforated are indicated in parentheses and are included in the total.

[d] Second shortest period of exposure to perforation. Both values are on the same sheet—top and bottom portions

Brunot Island (*Pittsburgh*), *Pa.* (*Last tabulated report in 1938*):

Table II (and Fig. 1) similarly records data for this test location. The one

Status.—(1) All classes show coating failure, and coatings have completely corroded away (100 per cent of surface areas rusted) from all specimens except

TABLE II.—SUMMARY OF SHEET FAILURES ON BRUNOT ISLAND, PA., TEST RACK[a].

Sheets Exposed April 21, 1926.

Description	Number of Specimens in Test	Average Life of Coating to First Rust, yr.	Average Time to Complete Removal of Coating, yr.	Time to First Perforation, yr.			Total Number of Sheets Failed Oct. 12, 1943, 17.48 yr.
				Average	Minimum	Maximum	
No. 16 gage, 2.50 oz. per sq. ft.	12	5.2	14.2	...	11.5	...	2
No. 22 gage, 2.50 oz. per sq. ft.	18	5.9	(14.2)[b]	...	...	...	0
No. 22 gage, 2.00 oz. per sq. ft.	18	4.6	11.6	...	14.0	...	2
No. 22 gage, 1.50 oz. per sq. ft.	18	3.5	8.6	(17.2)[b]	13.0	...	5
No. 22 gage, 1.25 oz. per sq. ft.	18	3.2	6.1	(17.0)[b]	13.0	...	6
No. 22 gage, 0.75 oz. per sq. ft.	14	2.2	4.2	(16.2)[b]	6.5	...	4
No. 28 gage, 0.75 oz. per sq. ft.	10	2.2	3.7	(11.3)[b]	4.0	...	8
No. 22 gage, uncoated	10	...	...	5.6	2.0	16.5	10

[a] A detailed record of failures of coating may be found in Table II of the 1938 Report; see *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 86 (1938). A record of uncoated sheet failures may be found in the 1940 Report, Table VI; see *Proceedings*, Am. Soc. Testing Mats., Vol. 40, p. 110 (1940).

[b] Figures shown in parentheses are not to be considered final as not all specimens in this weight of coating class have failed.

TABLE III.—RECORD OF COATING FAILURES ON SANDY HOOK, N. J., TEST RACK[a].

Sheets Exposed May 20, 1926.

Description	Number of Specimens in Test	Failures Observed				Total Number of Failures	Average Life of Coating, yr.
		Up to October, 1939,[b] 13.39 yr.	October, 1940, 14.40 yr.	April, 1942, 15.94 yr.	October, 1943, 17.42 yr.		
No. 16 gage, 2.50 oz. per sq. ft.	12	12	...	...	...	12	11.79
No. 22 gage, 2.50 oz. per sq. ft.	18	14	1	2	none	17	(12.90)[c]
No. 22 gage, 2.00 oz. per sq. ft.	18	18	...	...	...	18	9.96
No. 22 gage, 1.50 oz. per sq. ft.	18	18	...	...	...	18	7.63
No. 22 gage, 1.25 oz. per sq. ft.	18	18	...	...	...	18	6.80
No. 22 gage, 0.75 oz. per sq. ft.	14	14	...	...	...	14	4.77
No. 28 gage, 0.75 oz. per sq. ft.	10	10	...	...	...	10	4.89

[a] Columns representing intermediate inspections at which no new failures were observed have been omitted in this tabulation.

[b] A record of the coating failures observed at the inspections of April, 1938, to October, 1939, appears in Table I of the 1940 Report, see *Proceedings*, Am. Soc. Testing Mats., Vol. 40, p. 106 (1940). Earlier coating failures are recorded in the 1938 Report, see *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 87 (1938).

[c] Figures shown in parentheses are not to be considered final as not all specimens in this weight of coating class have failed.

TABLE IV.—RECORD OF COATING FAILURES ON STATE COLLEGE, PA., TEST RACK.

Sheets Exposed April 23, 1926.

Description	Number of Specimens in Test	Failures Observed				Total Number of Failures	Average Life of Coating, yr.
		Up to[a] October, 1941, 15.46 yr.	April 30, 1942, 16.02 yr.	October 20, 1942, 16.49 yr.	October 13, 1943, 17.47 yr.		
No. 16 gage, 2.50 oz. per sq. ft.	12	none	none	none	none	none	...
No. 22 gage, 2.50 oz. per sq. ft.	18	none	none	none	none	none	...
No. 22 gage, 2.00 oz. per sq. ft.	18	none	none	none	1	1	...
No. 22 gage, 1.50 oz. per sq. ft.	18	4	3	2	4	13	(16.72)[b]
No. 22 gage, 1.25 oz. per sq. ft.	18	16	none	2	...	18	14.69
No. 22 gage, 0.75 oz. per sq. ft.	14	14	...	...	...	14	10.04
No. 28 gage, 0.75 oz. per sq. ft.	10	10	...	...	...	10	11.20

[a] A record of the coating failures observed at the inspections of April, 1940, to October, 1941, inclusive, appears in Table III of the 1942 Report, see *Proceedings*, Am. Soc. Testing Mats., Vol. 42, p. 122 (1942). Earlier coating failures are recorded in the 1940 and 1938 reports, see *Proceedings*, Am. Soc. Testing Mats., Vol. 40, p. 107 (1940) and Vol. 38, Part I, p. 87 (1938).

[b] Figures shown in parentheses are not to be considered final as not all specimens in this weight of coating class have failed.

two. (2) All uncoated sheets have failed by perforation. (3) Perforation of originally coated sheets has occurred among the specimens of all weights of coating classes although largely confined to classes including and below the 1.50-oz.

Sandy Hook, N. J. (Last tabulated report in 1940):

At this location three additional coating failures were observed since the last report. These are recorded in Table III.

Status.—(1) All sheets show coating failure except one of those carrying a a 2.50-oz. coating. (2) All uncoated sheets are perforated. (3) None of the originally coated sheets has become perforated.

State College, Pa. (Last tabulated report in 1942):

Twelve additional coating failures were observed at this location. A record of these failures is shown in Table IV.

Status.—(1) One coating failure has now occurred in the 2.00-oz. coating class after 17.47 yr. of exposure. (2) All uncoated sheets are in an unperforated condition after 17.47 yr. of exposure. (3) All originally coated sheets have some coating remaining on them and are in an unperforated condition.

Key West, Fla. (Last tabulated report in 1942):

Eleven additional perforations of the type developing from corrosion of the under surface fully described in previous reports were observed at the April 4, 1944, inspection. A record of these perforations is shown in Table V.

Status.—(1) After 17.8 yr. perforation as indicated by a brown stain on the top surface in the vicinity of the lower purlin from corrosion originating on the underside has occurred among the specimens of the heavier weight of coating classes and is now found in all sheet groups except the No. 22 gage, 2.50-oz. group. The failures are confined largely to the 0.75-, 1.25-, and 1.50-oz. weight of coating classes. (2) Normal coating failures are appearing on the unperforated areas of the 0.75-oz. coated sheets. Of the 24 sheets in both gage groups in this class, 15 show coating failure (rusting from the top surface.) The areas rusted are small (maximum about 10 per cent of surface area). This indicates the life of 0.75-oz. coatings to

TABLE V.—RECORD OF INDICATIONS OF PERFORATION OF GALVANIZED SHEETS ON KEY WEST, FLA., TEST RACK[a].

Sheets Exposed June 9, 1926.

Description	Number of Specimens in Test	Perforations Observed		Total Number of Specimens Perforated	Time to First Perforation, yr.		
		Up to April 1941, 14.8 yr.	April 4, 1944, 17.8 yr.		Average	Minimum	Maximum
No. 16 gage, 2.50 oz. per sq. ft.	12	none	2	2	...	17.8	...
No. 22 gage, 2.50 oz. per sq. ft.	18	none	none	none	...	...	...
No. 22 gage, 2.00 oz. per sq. ft.	18[c]	2	4	6	(17.3)[b]	11.8	...
No. 22 gage, 1.50 oz. per sq. ft.	18	11	2	13	(14.8)[b]	11.8	...
No. 22 gage, 1.25 oz. per sq. ft.	18[c]	14	2	16	(13.8)[b]	10.6	...
No. 22 gage, 0.75 oz. per sq. ft.	14	12	1	13	(12.5)[b]	10.6	...
No. 28 gage, 0.75 oz. per sq. ft.	10	9	none	9	(12.9)[b]	10.6	...
No. 22 gage, uncoated	10	10	...	10	3.8	2.6	5.7

[a] Presence of yellow-brown stain showing through coating on upper surface from corrosion originating on the under side of sheets in the vicinity of the lower purlin. The sheets may neither be visibly perforated nor show coating failure on the top surface.

[b] Figures in parenthesis are not to be considered final as not all specimens in this weight of coating class have failed.

[c] Two sheets after 14.8 yr. removed from each of the groups marked (c). Among the total of four removed sheets, all showed indications of perforation except one of those in the 2.00-oz. class.

TABLE VI.—REPORT ON INSPECTIONS OF METALLIC COATINGS ON HARDWARE, STRUCTURAL

Abbreviations and Symbols Used: 0—no rust; 5, 10, 25, 100—approximate percentages; R—rusting of base metal; Y—yellow or e—edges; th—threads; Tr—trace; sl—slight; n—near;

Coating	Weight, oz. per sq. ft. of surface	Exposure at Brunot Island, Pa.				Exposure at Altoona, Pa.									
		1938		1939		1938		1939		1940		1941		1942	1938
		486 wks.	510 wks.	537 wks.	562 wks.	487 wks.	511 wks.	538 wks.	563 wks.	592 wks.	615 wks.	644 wks.	667 wks.		486 wks.
3 BY 3 BY 5/16-IN. PLAIN STEEL ANGLES															
Electrogalvanized	0.52														<10R
Hot-dip galvanized	2.52	Rack Damaged				Rack Damaged									0
Hot-dip aluminum	0.89														0
Cadmium plated	0.09	Specimens Mixed				Specimens Mixed									X
Electric sherardized	1.38														100Y
Lead plated	....														70R*
3 BY 3 BY 5/16-IN. COPPER-BEARING STEEL ANGLES															
Electrogalvanized	0.37				All Specimens Stolen from Brunot Island Racks	99R	99R	99R	100R	X	X	X	X	All Specimens Removed from Altoona Racks	<10R
Hot-dip galvanized	2.88	Rack Damaged				<10R	10R	10R 10Y	25R	25R	25R	25R	25R		0
Hot-dip aluminum	0.82					0d	0d	0d	0d	0d	0d	0d	0d		0
Cadmium plated	0.24	Specimens Mixed				X	X	X	X	X	X	X	X		80R
Electric sherardized	1.44					X	X	X	X	X	X	X	X		100Y
Lead plated	...					TrY	<10Y	10Y	10Y	10Y	10Y	20Y	20Y		80R*
2 BY 1½ by 3/16-IN. PLAIN STEEL ANGLES															
Electrogalvanized	0.53					X	X	X	X	X					40Ra
Electrogalvanized	0.50	Rack Damaged				X	X	X	X	X					20Ra
Hot-dip galvanized	3.24					TrY	TrR	TrR	TrR	...		Missing			0
Hot-dip aluminum	0.75					0d	0d	0d	0d	0d					0
Cadmium plated	0.43	Specimens Mixed				X	X	X	X	X					80R
Electric sherardized	1.21					X	X	X	X	X					20R 80Y
Lead plated	...					0d	0d	0d	0d	0d					50R*
2 BY 1½ BY 3/16-IN. COPPER-BEARING STEEL ANGLES															
Electrogalvanized	0.70	X	X	X		X	X	X	X	X	X	X	X		20Ra
Electrogalvanized	0.76	X	X	X		X	X	X	X	X	X	X	X		15Ra
Hot-dip galvanized	2.75	<10R	<10R	<10R		<10R	<10R	10R	10R	15R 15Y	20R	15R 20Y	30R		0
Hot-dip aluminum	0.50	0d	0d	0d		0d	0d	0d	0d	0d	0d				0
Cadmium plated	0.50	X	X	X		X	X	X	X	X	X	Missing			80R
Electric sherardized	1.15	X	X	X		X	X	X	X	X	X				X
Gas sherardized	0.17	X	X	X		X	X	X	X	X	X				...
Lead plated	....	50R*	45R*	60R*		0d	0d	0d	0d	0d	0d				60R*
2-IN. DIAMETER TUBULAR GOODS															
Electrogalvanized	1.58	95R	99R	99R		98R	99R	99R	100R	X	X	X	X		0
Hot-dip galvanized	2.51	45Y	80Y	TrR 80Y		15R	30R	20R	40R	40R	40R	40R 60Y	80R		0
Hot-dip aluminum	4.73	0d	0d	0d		0d	0d	0d	0d	0d	0d	0d	0d		0
Cadmium plated	0.23	X	X	X		X	X	X	X	X	X	X	X		80R
Cadmium plated	0.10	X	X	X		X	X	X	X	X	X	X	X		90R
Electric sherardized	0.29	X	X	X		X	X	X	X	X	X	X	X		99R
Electric sherardized	0.85	X	X	X		X	X	X	X	X	X	X	X		100R
Gas sherardized	0.66	90R	70R*	60R*		90R	95R	95R	95R	95R	95R	95R	100R		100Y
Lead plated	...	50R*	70R*	75R*		0d	0d	0d	0d	0d	<10R*	5R	<10R*		70R*
1-IN. DIAMETER TUBULAR GOODS															
Electrogalvanized	1.62	70R	75R	80R		70R	85R	90R	90R	90R	99R	100R	X		
Hot-dip galvanized	1.83	95R	95R	96R		X	X	X	X	X	X	100R	X		
Hot-dip aluminum	1.83	0d	0d	0d		0d	0d	0d	0d	0d	0d	0d	0d		
Cadmium plated	0.30	X	X	X		X	X	X	X	X	X	X	X		
Cadmium plated	1.18	X	X	X		X	X	X	X	X	X	X	X		
Electric sherardized	0.42	X	X	X		X	X	X	X	X	X	X	X		
Electric sherardized	0.92	X	X	X		80R	85R	90R	90R	90R	90R	90R	90R		
Gas sherardized	0.72	X	X	X		80R	90R	90R	90R	90R	90R	90R	90R		
Calorized	...	0d	0d	0d		0d	0d	0d	0d	0d	0d	0d	0d		
Lead plated	...	35R*	30R*	50R*		0d	0d	0d	0d	0d	0d	0d	0d		
Amaloy	...	70R*	70R*	75R*		0d	0d	0d	0d	0d	0d	0d	0d		

SHAPES, TUBULAR GOODS, ETC., EXPOSED TO ATMOSPHERE ON TEST RACKS AT FIVE LOCATIONS.

orange-yellow rust; *— rust spots widely distributed; d—black or dark surface film (soot or dirt); a—in angle; <—less than; s—stain; X—100 per cent rust previously observed.

Exposure at State College, Pa.							Exposure at Sandy Hook, N. J.									Exposure at Key West, Fla.		
1938	1939		1940		1941		1938		1939		1940		1941		1942	1938	1940	1941
510 wks.	537 wks.	562 wks.	591 wks.	614 wks.	643 wks.	666 wks.	487 wks.	511 wks.	538 wks.	563 wks.	594 wks.	615 wks.	644 wks.	667 wks.	720 wks.	464 wks.	571 wks.	623 wks.
3 by 3 by 5/16-in. Plain Steel Angles																		
<10R	10Ra	10Ra	10Ra	10Ra	10Ra	15Ra	35R	35R	35R	40R	40R	40R	70R	70R	Missing	TrY	TrR	<10R
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		96R	98R	99R
100Y	100Y	100Y	100Y	100Y	100n R	100n R	100Y	100Y	100Y	10R 90Y	10R 90Y	10R 90Y	10R 90Y	10R 90nR		<10R	<10R	<10R
75R*	75R*	85R*	85R*	85R*	85R*	85R*	35R	50R*	45R*	50R*	60R*	60R*	70R*	60R*		<10R*	30R*	30R*
3 by 3 by 5/16-in. Copper-Bearing Steel Angles																		
<10R	10Ra	10Ra	10Ra	10Ra	10Ra	10Ra	30R	30R	30R	30R	30R					<10R	<10R	<10R
0	0	0	0	0	0	0	0	0	0	0	0					0	0	0
0	0	0	0	0	0	0	0	0	0	0	...	Rack Damaged				0	0	0
85R	75R	85R	80R	80R	85R 15Y	85R	X	X	...	...	...	Specimens Mixed				35R	50R	50R
<10R	100Y	100Y	100Y	100Y	100nR	100Y	100Y	1R 99Y	...	...	...	...	...	...	...	<10R	<10R	<10R
65R*	75R*	80R*	80R*	75R*	85R*	75R*	90R*	80R*	...	...	...	...	...	...	...	60R*	60R*	30R*
2 by 1½ by 3/16-in. Plain Steel Angles																		
45Ra	45Ra	45R	45R	45R	60R	60R	70R	75R	70R	60R	75R	75R	75R	75R	Rack Down	10Ra	15R	15R
15R 15Y	40R	45R	45R	60R	75R	70R	85R	85R	100R	100R	X	X	X	X		10Ra	30R	40R
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		TrR	TrR	TrR
80R	80R	95R	90R	90R	98R	90R	X	X	X	X	X	X	X	X		60R	95R	95R
20R	40R	40R	30R	40R	50R	60R	X	X	X	X	X	X	X	X		20R	30R	30R
80Y	60Y	60Y	70Y	60Y	50nR	40nR										80Y	70Y	70Y
50R*	55R*	75R*	75R*	75R*	75R*	80R*	70R*	70R*	65R*	60R*	60R*	60R*	75R*	75R*		18R*	15R*	15R*
2 by 1½ by 3/16-in. Copper-Bearing Steel Angles																		
20Ra	30Ra	35Ra	35Ra	35Ra	30R	55R	60R	60R	60R	60R	65R	65R	65R	65R	Rack Down	<10Ra	15R	15R
20Ra	30R	35Ra	35Ra	40R	35R	50R	60R	60R	70R	75R	80R	80R	80R	80R		11Ra	20R	20R
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	TrR	TrR
80R	80R	85R	85R	85R	85R	85R	X	X	X	X	X	X	X	X		55R	60R	60R
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
...	...	...	...	...	...	...	X	X	X	X	X	X	X	X		X	X	X
75R*	70R*	75R*	75R*	75R*	75R*	80R*	20R*	50R*	55R*	60R*	50R*	55R*	55R*	75R*		45R*	30R*	30R*
2-in. Diameter Tubular Goods																		
0	0	0	0	0	0	0										0	0	0
0	0	0	0	0	0	0										0	0	0
0	0	0	0	0	0	0										<10Y	TrR	TrR
90R	90R	95R	95R	100R	100R	X					Rack Damaged					20R	60R	60R
90R	90R	90R	95R	100R	X	X										80R	90R	90R
99R	99R	99R	100R	X	X	X					Specimens Mixed					X	X	X
X	X	X	X	X	X	X										100nR	100nR	100nR
100Y	100Y	100Y	100Y	100Y	100Y	100Y										100nR	100nR	100nR
85R*	85R*	90R*	90R*	90R*	95R*	90R*										40R*	30R*	30R*
1-in. Diameter Tubular Goods																		
																	0	0
																0	0	TrY
																TrR	TrR	TrR
																95R	99R	99R
																TrR	TrR	TrR
			Rack Damaged								Rack Damaged					95R	100R	X
																100nR	100nR	100nR
			Specimens Mixed								Specimens Mixed					100nR	100nR	100nR
																100Y	100nR	100nR
																40R*	40R*	40R*
																30R*	30R*	30R*

TABLE VI.—REPORT ON INSPECTIONS OF METALLIC COATINGS ON HARDWARE, STRUCTURAL SHAPES,

Abbreviations and Symbols Used: 0—no rust; 5, 10, 25, 100—approximate percentages; R—rusting of base metal; Y—yellow or
e—edges; th—threads; Tr—trace; sl—slight; n—near;

Coating	Weight, oz. per sq. ft. of surface	Exposure at Brunot Island, Pa.				Exposure at Altoona, Pa.									
		1938		1939		1938		1939		1940		1941		1942	1938
		486 wks.	510 wks.	537 wks.	562 wks.	487 wks.	511 wks.	538 wks.	563 wks.	592 wks.	615 wks.	644 wks.	667 wks.		486 wks.
FORGED STEEL TOWER FITTINGS															
Electrogalvanized Bolt Nut Clamp	0.31 0.54 1.15	X	X	X		X	X	X	X	X	X	X	X		TrR
Electrogalvanized Bolt Nut Clamp	0.02 0.01 0.46	98R	99R	99R		X	X	X	X	X	X	X	X		<10R
Hot-dip galvanized	2.67	25R 75Y	25R 75Y	25R 75Y		40R 60Y	40R 60Y	50R 50Y	70R 30Y	60R 40Y	80R 20Y	98R	95R 5Y		0
Hot-dip galvanized	1.53	99R	100R	X		100R	X	X	X	X	X	X	X		15Y
Hot-dip aluminum		0d	0d	0d		0d	0d	0d	0d	0d	0d	0d	0d		0
Cadmium plated	0.40	X	X	X		X	X	X	X	X	X	X	X		10R
Electric sherardized	0.50	70R 30Y	95R	96R		50R	85R	90R	90R	90R	95R	98R	98R		100Y
Gas sherardized	...	X	X	X		X	X	X	X	X	X	X	X		90R 10Y
Parkerized	...	X	X	X		X	X	X	X	X	X	X	X		X
Cadmium plated	0.26	X	X	X		X	X	X	X	X	X	X	X		98R
Lead plated	...	X	X	X		X	X	X	X	X	X	X	X		X
¾-IN. NIPPLES AND ELLS															
Electrogalvanized MI Nipple Ell	1.64 1.55	70R	80R	80R	All Specimens Stolen from Brunot Island Racks	90R	85R	85R	95R	100R	X	X	X	All Specimens Removed from Altoona Racks	0
Electrogalvanized CI Nipple Ell	2.02 2.36	40R	30R	60R		30R	30R	40R	60R	75R	85R	90R	85R		0
Electrogalvanized MI Nipple Ell	2.43 2.90	85R	95R	92R		100R	X	X	X	X	X	X	X		<10R
Electrogalvanized CI Nipple Ell	1.82 0.67	85R	90R	90R		80R	85R	90R	100R	X	X	X	X		<10R
Hot-dip galvanized MI	1.82	70R	80R	90R		80R 20Y	95R	90R 10Y	100R	X	X	X	X		0
Hot-dip galvanized CI	1.44	80R	98R	98R		80R 20Y	90R	100R 10Y	100R	X	X	X	X		0
Hot-dip aluminum MI	3.20	0d	0d	0d		0d	0d	0d	0d	0d	0d	0d	0d		Rth
Hot-dip aluminum CI	2.80	0d	0d	0d		0d	0d	0d	0d	0d	0d	0d	0d		Rth
Cadmium plated MI	...	X	X	X		X	X	X	X	X	X	X	X		100R
Cadmium plated CI	...	X	X	X		X	X	X	X	X	X	X	X		X
Cadmium plated MI	...	...	...	...		X	X	X	X	X	X	...	...		X
Cadmium plated CI	...	...	...	...		X	X	X	X	X	X	...	...		X
Electric sherardized MI	0.63	X	X	X		X	X	X	X	X	X	...	...		100Y
Electric sherardized CI	0.47	X	X	X		X	X	X	X	X	X	...	...		50R 50Y
Gas sherardized MI	0.78	X	X	X		X	X	X	X	X	X	...	...		50R 50Y
Gas sherardized CI	0.84	X	X	X		X	X	X	X	X	X	...	...		70R 30Y
Parkerized MI	...	X	X	X		X	X	X	X	X	X	...	...		X
Parkerized CI	...	X	X	X		80R*	85R	80R	100R	X	X	...	...		X
Electric sherardized MI	0.75	75R	95R	95R		80R	85R	90R	95R	100R	X	...	...		100Y
Electric sherardized CI	0.82	85R	90R	94R		80R	90R	90R	95R	100R	X	X	X		35R 65Y
Amaloy MI	...	30R*	40R*	50R*		0d	0d	0d	0	0d	0d	Y	<10R		90R*
Amaloy CI	...	30R*	30R*	55R*		0d	0d	0d	0	0d	0d	Y	<10R		90R*
TOWER CLAMPS															
Electrogalvanized MI Bolt Nut Clamp	0.31 0.54 1.15	X	X	X		X	X	X	X	X	X	X	X		0
Electrogalvanize CI Bolt Nut Clamp	0.28 0.56 ...	X	X	X		X	X	X	X	X	X	X	X		0
Electrogalvanized MI Bolt Nut Clamp	0.02 0.01 0.46	X	X	X		X	X	X	X	X	X	X	X		20R
Electrogalvanized CI Bolt Nut Clamp	0.04 0.04 0.74	X	X	X		X	X	X	X	X	X	X	X		70R
Hot-dip galvanized MI	1.53	80R	90R	95R		X	X	X	X	X	X	X	X		0

TUBULAR GOODS, ETC., EXPOSED TO ATMOSPHERE ON TEST RACKS AT FIVE LOCATIONS—Continued

orange-yellow rust; *—rust spots widely distributed; d—black or dark surface film (soot or dirt); a—in angle; <—less than
s—stain; X—100 per cent rust previously observed.

Exposure at State College, Pa.							Exposure at Sandy Hook, N. J.									Exposure at Key West, Fla.		
1938	1939		1940		1941		1938		1939		1940		1941		1942	1938	1940	1941
510 wks.	537 wks.	562 wks.	591 wks.	614 wks.	643 wks.	666 wks.	487 wks.	511 wks.	538 wks.	563 wks.	594 wks.	615 wks.	644 wks.	667 wks.	720 wks.	464 wks.	571 wks.	623 wks.
FORGED STEEL TOWER FITTINGS																		
TrR	TrR	<10R	<10R	<10R	5R	10R	30R	35R	55R	60R	60R	70R	75R	80R		<10R	<10R	<10R
<10R	10R	10R	10R	10R	10R	20R	60R	70R	70R	80R	80R	80R	80R	85R		0	0	0
0	0	0	0	0	0	0	10Y	15Y	20Y	15Y	30Y	25Y	40Y	. . .		13R	10R	10R
15Y	35Y	40Y	40Y	65Y	50Y	60Y	70Y	80Y	95Y	100Y	100Y	100Y	100Y	TrR		TrY	TrY	TrY
0	0	0	0	0	0	0	0	0	0	0	TrY	TrY	5Y	. . .		20Y	40Y	40Y
15R	25R	30R	40R	45R	45R	60R	X	X	X	X	X	X	X			20R	30R	40R
85Y	100Y	100Y	100Y	100Y	100nR	100nR	100Y	TrR	5R	5R	5R	30R	35R	50R		100Y	100Y	100Y
								98Y	95Y	95Y	95Y	70Y	65Y	50Y				
80R	100R	X	X	X	X	X	X	X	X	X	X	X	X	X		100nR	100nR	5R
20Y																		95Y
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
100R	X	X	X	X	X	X	95R	100R	X	X	X	X	X	X		80R	70R	70R
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
¾-IN. NIPPLES AND ELLS																		
0	0	0	0	0	0	0	TrR	TrR	<10R	<10R	<10R	<10R	2R	<10R		0	<10R	<10R
													5Y					
0	0	0	0	0	0	0	TrR	TrR	<10R	<10R	<10R	<10R	2R	<10R		0	<10R	<10R
													5Y					
<10R	<10R	<10R	<10R	<10R	<10R	10R	35R	35R	35R	40R	40R	40R	40R	40R		<10R	0	0
<10R	<10R	<10R	<10	<10R	<10R	10R	65R	70R	65R	60R	60R	65R	65R	60R		<10R	<10R	<10R
20Y	25Y	20Y	25Y	50Y	40Y	50Y	70Y	75Y	75Y	70Y	70Y	80Y	5R	TrR	Rack Damaged Specimens Mixed	0	0	0
													85Y	100Y				
15Y	15Y	10Y	15Y	20Y	15Y	20Y	50Y	60Y	TrR	5R	5R	<10R	5R	10R		0	0	TrY
									99Y	95Y	95Y	90Y	50Y	90Y				
Rth	Rth	Rth	Rth	Rth	Rth	Rth	Rth	Rth	Rth	Rth	Rth	Rth	Rth	Rth		25R	20R	20R
Rth	Rth	Rth	Rth	Rth	Rth	Rth	Rth	Rth	Rth	Rth	Rth	Rth	Rth	Rth		30R	30R	30R
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		75R	100R	X
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		80R	100R	X
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		75R	95R	100R
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		90R	100R	X
15R	20R	20R	20R	10R	15R	15R	X	X	X	X	X	X	X	X		100Y	100Y	100Y
85Y	80Y	80Y	80Y	90Y	15nR	90nR												
35R	70R	50R	50R	50R	65R	65R	X	X	X	X	X	X	X	X		100Y	100Y	100Y
65Y	30Y	50Y	50Y	50Y	35Y	35Y												
65R	60R	50R	70R	70R	70R	75R	X	X	X	X	X	X	X	X		50R	100R	X
35Y	40Y	50Y	30Y	30Y		25Y										50Y		
85R	85R	90R	90R	100R	X	X	X	X	X	X	X	X	X	X		100R	X	X
15Y	15Y	10Y	10Y															
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		100R	X	X
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		100R	X	X
100Y	100Y	100Y	100Y	100Y	95nR	100Y	3R	<10R	10R	10R	10R	10R	10R	10R		100Y	100Y	100Y
							97Y	90Y	90Y	90Y	90Y	90Y	90Y	90Y				
30R	30R	30R	35R	30R	25R	30R	3R	<10R	10R	10R	20R	30R	. . .	. . .		78R	100R	X
70Y	70Y	70Y	65Y	70Y	60Y	70Y	97Y	85Y	90Y	90Y	80Y	70Y						
80R*	80R*	90R*	90R*	90R*	85R*	90R*	20R*	60R*	90R*	100R*	100R*	100R*	100R*	100R*		60R	70R	70R
80R*	80R*	90R*	90R*	90R*	85R*	90R*	20R*	60R*	90R*	100R*	100R*	100R*	100R*	100R*		. . .	70R	70R
TOWER CLAMPS																		
TrR	TrR	TrR	<10R	<10R	TrR	<10R	50R	50R	60R	60R	60R	65R	65R	65R		<10R	<10R	Samples Mixed When Racks Were Moved*
0	0	0	0	0	0	0	90R	90R	85R	90R	85R	90R	90R	99R		0	TrY	
35R	35R	35R	30R	35R	35R	25R	60R	65R	70R	70R	70R	70R	80R	75R		20R	10R	
																	20Y	
80R	65R	85R	85R	90R	80R	95R	90R	90R	95R	90R	90R	100R	X	X		47R	53R	
0	slY	10Y	10Y	10Y	25Y	30Y	40Y	50Y	50Y	50Y	70Y	60Y	50Y	60Y		TrR	<10Y	

TABLE VI.—REPORT ON INSPECTIONS OF METALLIC COATINGS ON HARDWARE, STRUCTURAL SHAPES,

Abbreviations and Symbols Used: 0—no rust; 5, 10, 25, 100—approximate percentages, R—rusting of base metal; Y—yellow or
e—edges; th—threads; Tr—trace; sl—slight; n—near;

Coating	Weight, oz. per sq. ft. of surface	Exposure at Brunot Island, Pa.				Exposure at Altoona, Pa.									
		1938		1939		1938		1939		1940		1941		1942	1938
		486 wks.	510 wks.	537 wks.	562 wks.	487 wks.	511 wks.	538 wks.	563 wks.	592 wks.	615 wks.	644 wks.	667 wks.		486 wks.
TOWER CLAMPS—Continued															
Hot-dip galvanized CI	1.75	50R 50Y	85R	70R	Brunot Island Racks	X	X	X	X	X	X	X	X	Altoona Racks	0
Hot-dip galvanized MI	2.00	10R 90Y	15R 85Y	10R 90Y		10R 90Y	15R 85Y	10R 90Y	15R 85Y	20R 80Y	20R 80Y	15R 85Y	30R 70Y		0
Hot-dip galvanized CI	2.38	10R 90Y	15R 85Y	10R 90Y		10R 80Y	15R 85Y	10R 90Y	15R 85Y	15R 85Y	15R 85Y	15R 85Y	20R 80Y		0
Cadmium plated MI	0.28	X	X	X		X	X	X	X	X	X	X	X		X
Cadmium plated CI	0.28	X	X	X		X	X	X	X	X	X	X	X		X
Cadmium plated MI	0.15	X	X	X		X	X	X	X	X	X	X	X		X
Cadmium plated CI	0.17	X	X	X		X	X	X	X	X	X	X	X		X
Electric sherardized MI	...	X	X	X		X	X	X	X	X	X	X	X		X
Electric sherardized CI	1.82	X	X	X		X	X	X	X	X	X	X	X		100Y
Gas sherardized MI	0.50	X	X	X		X	X	X	X	X	X	X	X		90R
Gas sherardized CI	0.63	X	X	X		X	X	X	X	X	X	X	X		90R
Parkerized MI	...	X	X	X		X	X	X	X	X	X	X	X		X
Parkerized CI	...	X	X	X		X	X	X	X	X	X	X	X		X
Hot-dip aluminum MI	3.16	0d	0d	0d		0d	0d	0d	0d	0d	0d	0d	0d		0
Hot-dip aluminum CI	2.51	0d	0d	0d		0d	0d	0d	0d	0d	0d	0d	0d		0
Amaloy MI	...	X	X	X		X	X	X	X	X	X	X	X		X
Amaloy CI	...	X	X	X		X	X	X	X	X	X	X	X		X
1½ BY 1½ BY ⅛-IN. PLAIN STEEL ANGLES															
Electrogalvanized	0.47	X	X	X	Stolen from	X	X	X	X	X	X	X	X	Removed from	30R
Electrogalvanized	1.09	X	X	X		X	X	X	X	X	X	X	X		0
Hot-dip galvanized	3.16	<10R	<10R	<10R		<10R	<10R	10R	20R	...	...	...	...		0
Hot-dip aluminum	0.89	0d	0d	...		0d	0d	0d	0d	0d	0d	0d	0d		0
Cadmium plated	0.12	X	X	X		X	X	X	X	X	X	X	X		75R
Electric sherardized	0.14	X	X	X		X	X	X	X	X	X	X	X		65R
Gas sherardized	...	X	X	X		X	X	X	X	X	X	X	X		X
Lead plated	...	20R*	25R*	20R*		10R*	20R*	15R*	10R*	10R*	10R*	10R*	15R*		40R*
1½ BY 1½ BY ⅛-IN. COPPER BEARING STEEL ANGLES															
Electrogalvanized	0.76	X	X	X	All Specimens	X	X	X	X	X	X	X	X	All Specimens	30R
Electrogalvanized	0.47	X	X	X		X	X	X	X	X	X	X	X		35R
Hot-dip galvanized	3.20	10Y	20Y	15Y		10R	10R	10R	10R	10R	15R	15R	20R		0
Hot-dip aluminum	1.11	0d	X	X		0d	0d	0d	0d	0d	0d	0d	0d		0
Cadmium plated	0.65	X	X	X		X	X	X	X	X	X	X	X		70R
Electric sherardized	...	...	...	...		X	X	X	X	X	X	X	X		10R
Gas sherardized	...	...	...	...		...	...	...	...	...	...	...	...		...
Lead plated	...	20R*	30R*	35R*		0d	0d	0d	0d	0d	0d	0d	0d		60R*
NO. 14 BY 2½-IN. PLAIN STEEL FLATS															
Electrogalvanized	0.45	X	X	X		X	X	X	X	X	X	X	X		0
Electrogalvanized	0.70	95R	98R	98R		98R	98R	98R	100R	X	X	X	X		0
Hot-dip galvanized	3.16	20R	15R 40Y	15R 60Y		10R	15R	20R 25Y	30R 70Y	30R 70Y	40R 60Y	60R	65R 35Y		0
Hot-dip aluminum	0.89	...	...	...		0d	0d	0d	0d	0d	0d	0d	0d		0
Cadmium plated	...	X	X	X		X	X	X	X	X	X	X	X		65R
Electric sherardized	0.58	X	X	X		X	X	X	X	X	X	X	X		5R 95Y
Gas sherardized	...	X	X	X		X	X	X	X	X	X	X	X		15R 85Y
Lead plated	...	10R*	15R*	15R*		0d	0d	0d	0d	0d	0d	0d	0d		15R*
NO. 14 BY 2½-IN. COPPER-BEARING STEEL FLATS															
Electrogalvanized	0.29	X	X	X		X	X	X	X	X	X	X	X		<10R
Electrogalvanized	0.62	90R	95R	98R		X	X	X	X	X	X	X	X		0
Hot-dip galvanized	3.20	20R	15R 40Y	15R 60Y		15R	20R	20R 25Y	30R 70Y	25R 75Y	30R 70Y	50R 40Y	75R 25Y		0
Hot-dip aluminum	0.47	0d	0d	0d		0d	0d	0d	0d	0d	0d	0d	0d		0
Cadmium plated	...	X	X	X		X	X	X	X	X	X	X	X		80R
Electric sherardized	...	X	X	X		X	X	X	X	X	X	X	X		15R 85Y
Gas sherardized	...	X	X	X		X	X	X	X	X	X	X	X		100Y
Lead plated	...	10R*	10R*	15R*		0d	0d	0d	0d	0d	0d	0d	0d		15R*

TUBULAR GOODS, ETC., EXPOSED TO ATMOSPHERE ON TEST RACKS AT FIVE LOCATIONS—Continued

orange-yellow rust; *—rust spots widely distributed; d—black or dark surface film (soot or dirt); a—in angle; <—less than; s—stain; X—100 per cent rust previously observed.

Exposure at State College, Pa.							Exposure at Sandy Hook, N. J.									Exposure at Key West, Fla.		
1938	1939		1940		1941		1938		1939		1940		1941		1942	1938	1940	1941
510 wks.	537 wks.	562 wks.	591 wks.	614 wks.	643 wks.	666 wks.	487 wks.	511 wks.	538 wks.	563 wks.	594 wks.	615 wks.	644 wks.	667 wks.	720 wks.	464 wks.	571 wks.	623 wks.
Tower Clamps—Continued																		
0	slY	0	10Y	10Y	15Y	10Y	40Y	40Y	50Y	50Y	50Y	50Y	50Y	<10R	Rack Damaged Specimens Mixed	0	0	...
0	0	0	0	0	TrY	TrY	0	0	0	15Y	20Y	20Y	25Y	60Y		0	0	Samples Mixed When Racks Were Moved
0	0	0	0	0	0	0	0	0	0	15Y	20Y	20Y	15Y	20Y		0	0	
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		67R	97R	
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		80R	100R	
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	
<10R 95Y	50R 50Y	50R 50Y	50R 50Y	100R	X	X	X	X	X	X	X	X	X	X		10R 90Y	90R	
90R	90R 10Y	100R	X	X	X	X	X	X	X	X	X	X	X	X		100Y	90R	
90R	90R 10Y	100R	X	X	X	X	X	X	X	X	X	X	X	X		100R	X	
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		100R	X	
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		100R	...	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		...	33R 67Y	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		...	87R	
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	
1½ by 1½ by ⅛-in. Plain Steel Angles																		
30R	30R	40R	50R	50R	40R	60R	65R	65R	65R	70R	70R	75R	80R	85R		<10R	20R	20R
0	TrR	TrR	<10R	<10R	10R	10R	80R	75R	80R	80R	85R	90R	90R	98R		TrY	TrR	<10R
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0
75R	80R	80R	80R	80R	90R	85R	X	X	X	X	X	X	X	X		35R	50R	50R
65R	65R	65R	80R	80R	95R	75R	X	X	X	X	X	X	X	X		100nR	100nR	100nR
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
30R*	40R*	50R*	50R*	60R*	80R*	60R*	40R*	45R*	50R*	40R*	40R*	40R*	40R*	55R*		40R*	30R*	30R*
1½ by 1½ by ⅛-in. Copper-Bearing Steel Angles																		
25R	25R	35R	35R	35R	25R	40R	60R	60R	65R	60R	60R	70R	75R	75R		0	<10R	<10R
30R	30R	40R	40R	50R	40R	50R	90R	90R	90R	95R	95R	98R	95R	100R		<10R	10R	15R
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	TrY	TrR	TrR
65R	65R	70R	70R	70R	75R- 15Y	85R	X	X	X	X	X	X	X	X	X	15R	20R	20R
15R	25R	30R	40R- 60Y	50R- 50Y	60R- 40Y	60R- 40nR	X	X	X	X	X	X	X	X	X	100nR	100nR	100nR
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
60R*	65R*	70R*	75R*	75R*	80R*	70R*	30R*	35R*	35R*	40R*	40R*	40R*	40R*	40R*	...	30R*	30R*	20R*
No. 14 by 2½-in. Plain Steel Flats																		
0	0	0	0				X	X	X	X	X	X	X	X	X	TrY	<10R	<10R
0	0	0	0				0	TrR	TrR	<10R	<10R	15R	35R	40R	45R	0	TrY	TrY
0	0	0	0				0	0	TrY	TrY	TrY	TrY	5Y	10Y	5Y	0	0	0
0	0	0	0				0	0	0	0	0	0	0	0	0	0	0	0
60R 20Y	80R 20Y	85R	90R				X	X	X	X	X	X	X	X	...	17R	25R	25R
15R 85Y	15R 85Y	20R 80Y	20R 80Y	Rack Down Specimens Mixed			X	X	X	X	X	X	X	X	...	5R 95Y	10R 90Y	15R 85Y
20R 80Y	25R 75Y	30R 70Y	30R 70Y				90R 10Y	95R 5Y	95R 5Y	95R 5Y	95R	98R	98R	100R	...	1R 99Y	5R 95Y	10R 90Y
20R*	20R*	30R*	30R*				20R*	35R*	40R*	35R*	40R*	50R*	40R*	50R*	40R*	15R*	15R*	15R*
No. 14 by 2½-in. Copper-Bearing Steel Flats																		
<10R	15R	35R	40R	45R	75R	80R	95R	99R	99R	100R	X	X	X	X	...	TrY	TrR	<10R
0	0	0	0	0	0	<10R	30R	35R	65R	70R	80R	95R				<10R	20R	40R*
0	0	0	0	0	0	0	0	0	0	0	TrY	TrY				0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0				0	0	0
90R	90R	90R	95R	95R	98R	95R	X	X	X	X	X	X				85R	85R	85R
25R 25Y	20R 80Y	30R 70Y	40R 60Y	40R 60Y	90R 10Y	95R 5Y	X	X	X	X	X	X	Rack Down Specimens Mixed			5R 95Y	15R 85Y	20R 80Y
100Y	100Y	<10R 90Y	<10R 90Y	10R 90Y	TrR 98Y	10R 98nR	70R 30Y	90R 10Y	90R 10Y	90R 10Y	90R	90R 10Y				5R 95Y	15R 85Y	20R 80Y
30R*	25R*	30R*	30R*	30R*	35R*	40R*	25R*	35R*	40R*	35R*	40R*	45R*				15R*	15R*	15R*

TABLE VI.—REPORT ON INSPECTIONS OF METALLIC COATINGS ON HARDWARE, STRUCTURAL SHAPES,
Abbreviations and Symbols Used: 0—no rust; 5, 10, 25, 100—approximate percentages; R—rusting of base metal; Y—yellow or
e—edges; th—threads; Tr—trace; sl—slight; n—near;

Coating	Weight, oz. per sq. ft. of surface	Exposure at Brunot Island, Pa.				Exposure at Altoona, Pa.									
		1938		1939		1938		1939		1940		1941		1942	1938
		486 wks.	510 wks.	537 wks.	562 wks.	487 wks.	511 wks.	538 wks.	563 wks.	592 wks.	615 wks.	644 wks.	667 wks.		486 wks.
¼ by 6-in. Bolts															
Sherardized	1.10	65R	70R	70R		X	X	X	X	X	X	X	X		10R 90Y
Sherardized	0.68	X	X	X		X	X	X	X	X	X	X	X		40Y
Hot-dip galvanized	1.61	X	X	X		X	X	X	X	X	X	X	X		0
Electrogalvanized	0.33	X	X	X		X	X	X	X	X	X	X	X		X
Cadmium plated	0.29	X	X	X		X	X	X	X	X	X	X	X		X
Cadmium plated	0.22	X	X	X		X	X	X	X	X	X	X	X		40R
⅝ by 2½-in. Bolts															
Sherardized	0.87	X	X	X	All Specimens Stolen from Brunot Island Racks	X	X	X	X	X	X	X	X	All Specimens Removed from Altoona Racks	30Y
Sherardized	0.70	75R	90R	90R		70R	70R	80R	90R	90R	95R	100R	X		65Y
Hot-dip galvanized	1.40	65R	50R 50Y	50R 50Y		60R	...	...	...	...	...	...	...		0
Cadmium plated	...	X	X	X		X	X	X	X	X	X	X	X		X
Cadmium plated	...	X	X	X		X	X	X	X	X	X	X	X		X
Electrogalvanized	0.20	X	X	X		X	X	X	X	X	X	X	X		X
½ by 2½-in. Bolts															
Sherardized	0.84	95R	100R	X		X	X	X	X	X	X	X	X		10Y
Sherardized	0.79	35R	30R	70R		50R	55R	90R	90R	95R	95R	100R	X		10Y
Hot-dip galvanized	1.48	90R	80R 20Y	80R		95R	65R	90R	90R	95R	95R	95R	100R		0
Electrogalvanized	0.21	X	X	X		X	X	X	X	X	X	X	X		95R
Electrogalvanized	0.20	X	X	X		X	X	X	X	X	X	X	X		90R
Cadmium plated	0.30	X	X	X		X	X	X	X	X	X	X	X		X
⅜ by 1½-in. Bolts															
Sherardized	1.20	15R	30R	60R		10R	15R	15R	50R	50R	50R	90R	100R		50Y
Sherardized	0.89	95R	100R	X		80R	70R	80R	80R	90R	100R	X	X		50Y
Hot-dip galvanized	1.45	95R	100R	X		80R	90R	90R	100R	X	X	X	X		0
Electrogalvanized	0.18	X	X	X		X	X	X	X	X	X	X	X		X
Cadmium plated	0.14	X	X	X		X	X	X	X	X	X	X	X		X
Cadmium plated	0.15	X	X	X		X	X	X	X	X	X	X	X		X
1-in Roofing Nails															
Sherardized	0.90	X	X	X		X	X	X	X	X	X				20R
Sherardized	0.86	X	X	X		X	X	X	X	X	X	Rack Damaged Specimens Mixed			20R
Cadmium plated	...	X	X	X		X	X	X	X	X	X				X
Hot-dip galvanized	1.34	X	X	X		X	X	X	X	X	X				0
Hot-dip galvanized	1.15	X	X	X		X	X	X	X	X	X				0
Electrogalvanized	...	X	X	X		X	X	X	X	X	X	X			X
Amaloy	...	20R*	20R*	20R*		...	30R*	20R*	20R*	20R*	30R*	...	30R*		X
No. 14 by 2½-in. Wood Screws															
Sherardized	0.94	X	X	X		X	X	X	X	X	X	X	X		10R
Sherardized	0.86	X	X	X		X	X	X	X	X	X	X	X		<10R
Cadmium plated	0.07	X	X	X		X	X	X	X	X	X	X	X		15R
Hot-dip galvanized	1.26	X	X	X		X	X	X	X	X	X	X	X		0
Cadmium plated	0.04	X	X	X		X	X	X	X	X	X	X	X		X
Hot-dip galvanized	...	X	X	X		X	X	X	X	X	X	X	X		0
Parkerized	...	X	X	X		X	X	X	X	X	X	X	X		X
Electrogalvanized	...	X	X	X		X	X	X	X	X	X	X	X		85R

TUBULAR GOODS, ETC., EXPOSED TO ATMOSPHERE ON TEST RACKS AT FIVE LOCATIONS—Continued

orange-yellow rust; *—rust spots widely distributed; d—black or dark surface film (soot or dirt); a—in angle; <—less than; s—stain; X—100 per cent rust previously observed.

Exposure at State College, Pa.							Exposure at Sandy Hook, N. J.									Exposure at Key West, Fla.		
1938	1939		1940		1941		1938		1939		1940		1941		1942	1938	1940	1941
510 wks.	537 wks.	562 wks.	591 wks.	614 wks.	643 wks.	666 wks.	487 wks.	511 wks.	538 wks.	563 wks.	594 wks.	615 wks.	644 wks.	667 wks.	720 wks.	464 wks.	571 wks.	623 wks.
¼ BY 6-IN. BOLTS																		
50R-50Y	50R	60R	90R	100R	X	X	X	X	X	X	X	X	X	X		X	X	X
100Y	100Y	100Y	100Y	100Y	25Y	TrR 100Y	50R 50Y	85R 15Y	98R	100R	X	X	X	X		100Y	100Y	100Y
0	0	0	TrY	TrY	5R 95Y	TrR 100Y	40Y	60Y	90Y	100Y	100Y	<10R	5R 95Y	20R 80Y		100Y	100Y	100Y
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
70R	80R	100R	X	X	X	X	X	X	X	X	X	X	X	X		0	TrR	10R
⅝ BY 2½-IN. BOLTS																		
70Y	80Y	100Y	100Y	100Y	75Y	100Y	5R 95Y	15R 85Y	30R 70Y	30R 70Y	40R 60Y	85R 15Y	85R	95R	Mixed	75Y	100Y	100Y
100Y	100Y	100Y	TrR 99Y	20R 80Y	75R 25Y	95R	X	X	X	X	X	X	X	X		X	X	X
0	0	0	TrY	TrY	25Y	20Y	0	TrY	TrY	30Y	60Y	65Y	60Y	80Y		0	0	0
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		0	<10R	<10R
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		80R	90R	95R
½ by 2½-IN. BOLTS																		
10Y	90Y	100Y	100Y	100Y	50Y	100Y	15R 85Y	30R 70Y	50R 50Y	80R	90R 10Y	99R	99R	100R	Specimens	50Y	Specimens Mixed	
30Y	90Y	100Y	100Y	100Y	95Y	20R 80Y	X	X	X	X	X	X	X	X		100nR		
0	TrY	TrY	TrY	TrY	20Y	TrY	0	TrY	TrY	25Y	60Y	65Y	70Y	80Y		0		
95R	95R	95R	95R	95R	100R	X	X	X	X	X	X	X	X	X		90R		
90R	95R	95R	100R	X	X	X	X	X	X	X	X	X	X	X		10R		
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X		
⅜ BY 1½-IN. BOLTS																		
50Y	95Y	100Y	100Y	10R	10R 75Y	60R 40Y	10R 90Y	30R 70Y	30R 70Y	60R 40Y	50R 50Y	100R	X	X	Damaged	95nR	100nR	100nR
50Y	55Y	100Y	100Y	100Y	50Y	100Y	X	X	X	X	X	X	X	X		100Y	100Y	100Y
0	0	0	0	0	10Y	TrY	0	TrY	TrY	25Y	60Y	65Y	90Y	100Y		0	0	0
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		50R-50Y	60R	90R
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
1-IN. ROOFING NAILS																		
50R	100R	X	X	X	Missing		X	X	X	X	X	X	X	X	Rack	Missing		
30R	20R	10R 90Y	...	...			X	X	X	X	X	X	X	X				
X	X	X	X	X			X	X	X	X	X	X	X	X				
0	0	0	0	0			...	...	...	...	...	...	...	...				
0	0	0	0	0			...	...	...	...	...	...	...	...				
X	X	X	X	X			X	X	X	X	X	X	X	X				
X	X	X	X	X			100R	X	X	X	X	X	X	X				
14 BY 2½-IN. WOOD SCREWS																		
20R	30R	40R	60R	70R	60R 40Y	70R	X	X	X	X	X	X	X	X	...	Missing		
<10R	10R	10R	30R	30R	20R 80Y	30R	X	X	X	X	X	X	X	X	...			
20R	25R	25R	25R	30R	35R	40R	X	X	X	X	X	X	X	X	...			
0	0	0	0	0	100Y	TrY	TrR 50Y	TrR 60Y	<10R 90Y	<10R 90Y	<10R 95Y	<10R 95Y	5R 95Y	10R 90Y	...			
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	...			
0	0	0	0	TrY	100Y	TrY	TrR 50Y	TrR 60Y	TrR 70Y	TrR 99Y	<10R 95Y	<10R 98Y	5R 95Y	10R 90Y	...			
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	...			
90R	90R	90R	90R	90R	95R	100R	...	...	...	...	...	...	...	...	...			

TABLE VI.—REPORT ON INSPECTIONS OF METALLIC COATINGS ON HARDWARE, STRUCTURAL SHAPES,

Abbreviations and Symbols Used: 0—no rust; 5, 10, 25, 100—approximate percentages; R—rusting of base metal; Y—yellow or e—edges; th—threads; Tr—trace; sl—slight; n—near;

Coating	Weight, oz. per sq. ft. of surface	Exposure at Brunot Island, Pa.				Exposure at Altoona, Pa.									
		1938		1939		1938		1939		1940		1941		1942	1938
		486 wks.	510 wks.	537 wks.	562 wks.	487 wks.	511 wks.	538 wks.	563 wks.	592 wks.	615 wks.	644 wks.	667 wks.		486 wks.
						KNOCKOUT BOXES									
Electrogalvanized	0.21	80R	20R	65R		90R	90R	90R	95R	95R	95R	98R	100R		0
Electrogalvanized	0.16	X	X	X		X	X	X	X	X	X	X	X		<10R
Hot-dip galvanized	1.56	35R 65Y	70R 30Y	70R 30Y		75R	75R	70R 30Y	90R 10Y	95R 5Y	95R 5Y	95R 5Y	100R		0
Cadmium plated	0.12	X	X	X		X	X	X	X	X	X	X	X		X
Cadmium plated	0.19	X	X	X		X	X	X	X	X	X	X	X		80R
Electric sherardized	0.28	X	X	X		X	X	X	X	X	X	X	X		90R 10Y
Gas sherardized	0.19	X	X	X		X	X	X	X	X	X	X	X		X
Electric sherardized	0.28	X	X	X		85R	85R	100R	X	X	X	X	X		100Y
Parkerized	...	X	X	X		100R	X	X	X	X	X	X	X		X
Amaloy	...	10R*	30R*	30R*		0d	0d	0d	0d	0d	0d	0d	0d		80R*
Hot-dip aluminum	1.84	0d	0d	0d		0d	0d	0d	0d	0d	0d	0d	0d		...
						STEEL HINGES									
Cadmium plated	0.29	X	X	X	All Specimens Stolen from Brunot Island Racks	X	X	X	X	X	X	X	X	All Specimens Removed from Altoona Racks	80R
Cadmium plated	0.32	X	X	X		X	X	X	X	X	X	X	X		...
Hot-dip galvanized	1.54	90R 10Y	100R	X		X	X	X	X	X	X	X	X		...
Electric sherardized	0.40	X	X	X		X	X	X	X	X	X	X	X		X
Gas sherardized	0.68	X	X	X		X	X	X	X	X	X	X	X		95R
Parkerized	...	X	X	X		X	X	X	X	X	X	X	X		X
Electrogalvanized	0.19	X	X	X		X	X	X	X	X	X	X	X		..
						BULLDOG CLAMPS									
Electrogalvanized	3.41	55R	60R	70R		80R	80R	80R	90R	90R	90R	95R	95R		...
Hot-dip galvanized	1.88	50R 50Y	95R	95R		X	X	X	X	X	X	X	X		...
Cadmium plated	0.22	X	X	X		X	X	X	X	X	X	X	X		X
Cadmium plated	0.17	X	X	X		X	X	X	X	X	X	X	X		X
Gas sherardized	0.46	X	X	X		X	X	X	X	X	X	X	X		100Y
Electric sherardized	1.25	X	X	X		X	X	X	X	X	X	X	X		100Y
Electric sherardized	0.58	X	X	X		X	X	X	X	X	X	X	X		100Y
Hot-dip aluminum	1.35	0d	0d	0d		0d	0d	0d	0d	0d	0d	0d	0d		0
Parkerized	...	X	X	X		20R	20R	20R	20R*	25R*	30R*	30R*	50R*		X
						¼ BY 3-IN. PLAIN STEEL FLATS									
Electrogalvanized	0.76	X	X	X		X	X	X	X	X	X	X	X		0
Electrogalvanized	0.45	X	X	X		X	X	X	X	X	X	X	X		0
Hot-dip galvanized	2.49	...	...	X		<10R	10R 25Y	10R 50Y	10R 80Y	10R 8Y	20R	5R 95Y	60R		0
Hot-dip aluminum	0.90	0d	0d	0d		0d	0d	0d	0d	0d	0d				0
Cadimum plated	0.23	X	X	X		X	X	X	X	X	X				90R 10Y
Electric sherardized	...	X	X	X		X	X	X	X	X	X	Missing			10R 90Y
Gas sherardized	0.12	X	X	X		X	X	X	X	X	X				X
Lead plated	...	35R*	30R*	30R*		0d	0d	0d	0d						60R*
						¼ BY 3-IN. COPPER-BEARING STEEL FLATS									
Electrogalvanized	0.84	X	X	X		X	X	X	X	X	X	X	X		0
Electrogalvanized	0.66	90R	97R	98R		X	X	X	X	X	X	X	X		0
Hot-dip galvanized	2.67	<10Y	<10Y	TrR 10Y		<10R	15R	10R 20Y	10R 30Y	10R 30Y	10R 50Y				0
Hot-dip aluminum	0.66	Od	Od	Od		0d	0d	0d	0d	...	...				0
Cadmium plated	0.27	X	X	X		X	X	X	X	X	X				90R
Electric sherardized	...	X	X	X		X	X	X	X	X	X	Missing			10R 90Y
Gas sherardized	0.18	X	X	X		X	X	X	X	X	X				X
Lead plated	...	40R*	30R*	35R*		0d	0d	0d	0d	0d	0d				40R*

TUBULAR GOODS, ETC., EXPOSED TO ATMOSPHERE ON TEST RACKS AT FIVE LOCATIONS—Continued

orange-yellow rust; *—rust spots widely distributed; d—black or dark surface film (soot or dirt); a—in angle; <—less than; s—stain; **X—100 per cent** rust previously observed.

Exposure at State College, Pa.							Exposure at Sandy Hook, N. J.									Exposure at Key West, Fla.		
1938	1939		1940		1941		1938		1939		1940		1941		1942	1938	1940	1941
510 wks.	537 wks.	562 wks.	591 wks.	614 wks.	643 wks.	666 wks.	487 wks.	511 wks.	538 wks.	563 wks.	594 wks.	615 wks.	644 wks.	667 wks.	720 wks.	464 wks.	571 wks.	623 wks.
KNOCKOUT BOXES																		
0	0	0	0	0	0	TrR	<10R	<10R	<10R	<10R	<10R	<10R	<10R	15R	...	0	TrR	TrR
<10R	<10R	<10R	10R	20R	25R 2Y	30R	80R	80R	85R	90R	95R	95R	95R	97R	...	10R	10R	10R
TrY	TrY	TrY	TrY	TrY	2Y	TrY	15Y	20Y	25Y	20Y	40Y	50Y	50Y	75R	...	0	0	0
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	...	93R	99R	99R
75R 25Y	80R	80R	80R	85R	100R	90R	X	X	X	X	X	X	X	X	...	10R	10R	10R
95R 5Y	90R	90R	100R	X	X	X	X	X	X	X	X	X	X	X	...	X	X	X
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	...	X	X	X
100Y	100Y	100Y	100Y	100Y	5R 95Y	100Y	100Y	100Y	100Y	100Y	100Y	100Y	100Y	100Y	...	100Y	100Y	100Y
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	...	X	X	X
60R*	60R*	80R*	80R*	80R*	98R*	100R	98R*	100R*	X	X	X	X	X	X	...	67R	100R	X
...	0d	0d	0d	0d	0d	0d	0	0	0	0	0	0	0	0	...	<10R	<10R	<10R
STEEL HINGES																		
Rack Down Samples Missing							X	X	X	X	X	X	X	X	...	30R	40R	60R
							X	X	X	X	X	X	X	X	...	10R	20R	20R
							30Y	60Y	60Y	60Y	85Y	90Y	90Y	X	...	0	0	0
							X	X	X	X	X	X	X	X	...	20R 80nR	100R	X
							20R 80Y	90R	95R	100R	X	X	X	X	...	5R 95nR	100nR	1R 99nR
							X	X	X	X	X	X	X	X	...	X	X	X
							X	X	X	X	X	X	X	X	...	X	X	X
BULLDOG CLAMPS																		
...	...	...	...	Rack Down Specimens Mixed			TrR	<10R	10R	10R	10R	15R	20R	25R	...	0	0	0
...	...	...	...				50Y	60Y	70Y	70Y	80Y	100Y	1R 99Y	TrR 100Y	...	0	0	0
X	X	X	X				X	X	X	X	X	X	X	X	...	X	X	X
X	X	X	X				X	X	X	X	X	X	X	X	...	X	X	X
100Y	100Y	100Y	10R 90Y				X	X	X	X	X	X	X	X	...	100Y	50R 50Y	50R 50Y
100Y	100Y	100Y	100Y				30R 70Y	60R 40Y	65R 35Y	65R 35Y	70R 30Y	70R 30Y	70R 30Y	100R	...	100Y	100Y	100Y
<10R	<10R	10R	10R				X	X	X	X	X	X	X	X	...	100Y	100Y	100Y
0	0	0	0				0	0	0	0	0	0	0	0	...	<10R	<10R	<10R
X	X	...	...				X	X	X	X	X	X	X	X	...	X	X	X
¼ BY 3-IN. PLAIN STEEL FLATS																		
0	0	0	TrY	<10R	10R 10Y	20R	65R	75R	90R	90R	95R	97R	98R	95R	...	TrR	<10R	<10R
0	0	0	TrY	<10R	<10R	10R	65R	70R	80R	80R	80R	85R	95R	95R 5Y	...	<10R	<10R	<10R
0	0	0	0	0	0	0	0	0	0	0	0	0	TrR	TrY	10R	0	TrR	TrR
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
95R	95R	95R	98R	98R	100R	X	X	X	X	X	X	X	X	X	...	<10R	10R	100R
10R 90Y	20R 80Y	25R 75Y	40R 60Y	40R 60Y	25R 75nR	70R 30Y	X	X	X	X	X	X	X	X	...	100Y	100Y	100Y
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	...	X	X	X
65R*	65R*	75R*	80R*	75R*	80R*	80R*	30R*	30R*	35R*	30R*	30R*	30R*	40R*	35R*	30R*	35R*	50R*	50R*
¼ BY 3-IN. COPPER-BEARING STEEL FLATS																		
0	0	0	TrY	<10R	10R 10Y	20R	60R	65R	75R	80R	80R	95R	95R	95R	...	0	0	0
0	0	0	0	0	0	TrY	50R	50R	55R	90R	90R	95R	95R	96R	...	0	0	TrR
0	0	0	0	0	0	0	0	0	0	0	TrY	TrY	0	TrY	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	TrY	TrR	TrR
95R	95R	95R	99R	99R	100R	X	X	X	X	X	X	X	X	X	...	15R	30R	50R
10R 90Y	20R 80Y	25R 75Y	30R 70Y	30R 70Y	25R 75nR	75R 25nR	X	X	X	X	X	X	X	X	...	100Y	100Y	100Y
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	...	X	X	X
50R*	65R*	65R*	65R*	60R*	80R*	70R*	30R*	35R*	35R*	30R*	40R*	40R*	40R*	40R*	35R*	30R*	30R*	30R*

TABLE VI.—REPORT ON INSPECTIONS OF METALLIC COATINGS ON HARDWARE, STRUCTURAL SHAPES,

Abbreviations and Symbols Used: 0—no rust; 5, 10, 25, 100—approximate percentages; R—rusting of base metal; Y—yellow or
e—edges; th—threads; Tr—trace; sl—slight; n—near;

Coating	Weight, oz. per sq. ft. of surface	Exposure at Brunot Island, Pa.					Exposure at Altoona, Pa.									
		1938		1939			1938		1939		1940		1941		1942	1938
		486 wks.	510 wks.	537 wks.	562 wks.		487 wks.	511 wks.	538 wks.	563 wks.	592 wks.	615 wks.	644 wks.	667 wks.		486 wks.
No. 209 Window Frame Sections																
Electrogalvanized	0.67	Missing				Island Racks	X	X	X	X	X	X	Rack Down Specimens Mixed		Altoona Racks	<10Ra
Electrogalvanized	0.24						X	X	X	X	X	X				<10R
Hot-dip galvanized	3.10						<10R	<10R	10R 20Y	10R 30Y	10R 30Y	10R 50Y				0
Hot-dip aluminum	0.61						0d	0d	0d	0d	..	...				0
Cadmium plated	0.21						X	X	X	X	X	X				70R
Electric sherardized	0.52						X	X	X	X	X	X				3R 97Y
Amaloy	...						TrY	TrY	TrY	0d	0d	...				50R*
No. 792 Window Frame Sections																
Electrogalvanized	0.54	Missing				Stolen from Brunot	X	X	X	X	X	X	X	X	Removed from	30Ra
Electrogalvanized	0.35						X	X	X	X	X	X	X	X		40R
Hot-dip galvanized	2.60						10R 20Y	15R 30Y	15R 30Y	40R 60Y	40R 60Y	40R 60Y	70R	40R 60Y		0
Hot-dip aluminum	1.39						0d	0d	0d	0d	0d	0d	0d	0d		0
Cadmium plated	0.22						X	X	X	X	X	X	X	X		30R
Cadmium plated	0.17						X	X	X	X	X	X	X	X		90R
Electric sherardized	0.57						X	X	X	X	X	X	X	X		100Y
Gas sherardized	0.53						X	X	X	X	X	X	X	X		60R 40Y
Parkerized	...						X	X	X	X	X	X	X	X		X
No. 161 Window Frame Sections																
Electrogalvanized	0.89	X	X	X		All Specimens	Rack Damaged Specimens Mixed								All Specimens	50R
Electrogalvanized	0.81	X	X	X												60R
Hot-dip galvanized	2.97	<10R	<10R	10R												0
Hot-dip aluminum	0.66	0d	0d	0d												0
Cadmium plated	0.22	X	X	X												90R
Cadmium plated	0.15	X	X	X												85R
Electric sherardized	0.32	X	X	X												100Y
Gas sherardized	0.42	X	X	X												TrR 98Y
Parkerized	...	X	X	X												X

be of the order of 17 to 18 yr. at this location. (3) All uncoated sheets had previously been perforated (average time 3.8 yr.).

EXPOSURE TESTS OF METALLIC COATED HARDWARE

The inspection of metallic coated hardware, structural shapes, tubular goods, etc., has been carried out on the dates of the scheduled visits made to test plots for inspecting galvanized sheets.

The last tabulation of data showing the progress of rusting on test pieces was issued with the 1938 report.[2] In 1942 the test racks at State College, Pa., and Sandy Hook, N. J., were rebuilt. Only those specimens which appeared to merit further testing were remounted. The arrangement of the specimens on the reconstructed racks was shown in Tables III and IV of the 1943 Report of Committee A-5.[3]

The present report extends the tabulation of the observations to the time of remounting, October, 1942. These data will be found in Table VI. A brief summary of the status of the tests at each location at that time follows. It is

---

[2] *Proceedings*, Am. Soc. Testing Mats., Vol. 38, p. 84 (1938).

[3] *Proceedings*, Am. Soc. Testing Mats., Vol. 43, pp. 74 and 76 (1943).

TUBULAR GOODS, ETC., EXPOSED TO ATMOSPHERE ON TEST RACKS AT FIVE LOCATIONS—Concluded

orange-yellow rust; *—rust spots widely distributed; d—black or dark surface film (soot or dirt); a—in angle; <—less than; s—stain; X—100 per cent rust previously observed.

Exposure at State College, Pa.							Exposure at Sandy Hook, N. J.									Exposure at Key West, Fla.		
1938	1939		1940		1941		1938		1939		1940		1941		1942	1938	1940	1941
510 wks.	537 wks.	562 wks.	591 wks.	614 wks.	643 wks.	666 wks.	487 wks.	511 wks.	538 wks.	563 wks.	594 wks.	615 wks.	644 wks.	667 wks.	720 wks.	464 wks.	571 wks.	623 wks.
NO. 209 WINDOW FRAME SECTIONS																		
10Ra	15Ra	30R	25R	Rack Down Specimens Mixed			Rack Down Specimens Mixed									15R	20R	25R
<10Ra	<10R	10Ra	10R													<10R	<10R	10R
0	0	0	0													0	0	0
0	0	0	0													0	0	0
75R	80R	90R	90R													65R	80R	80R
10R	15R	25R	30R													100Y	100Y	100Y
90Y	85Y	75Y	70Y															
75R*	70R*	80R*	80R*													40R*	40R*	40R*
NO. 792 WINDOW FRAME SECTIONS																		
35Ra	35Ra	40Ra	...	Rack Down Specimens Mixed			95R	97R	98R	99R	99R	99R	100R	X	X	10R	10R	15R
40R	45Ra	50R	50R				97R	99R	99R	100R	X	X	X	X	X	75R	75R	75R
0	0	0	0				0	0	0	0	TrY	TrY	5Y	TrY	10Y	0	0	0
0	0	0	0				0	0	0	0	0	0	0	0	0	0	0	0
35R	35R	50R	50R				X	X	X	X	X	X	X	X	X	15R	25R	30R
90R	90R	90R	95R				X	X	X	X	X	X	X	X	X	70R	80R	40R
100Y	100Y	100Y	100Y				X	X	X	X	X	X	X	X	X	100Y	100Y	100Y
70R	70R	90R	85R				10R	15R	20R	30R	30R	60R	60R	90R	100R	40R	40R	40R
							90Y	85Y	80Y	70Y	70Y	40Y	40Y	10nR		60Y	60Y	60Y
X	X	X	X				X	X	X	X	X	X	X	X	X	X	X	X
NO. 161 WINDOW FRAME SECTIONS																		
50R	50R	60R	60R	60R	75R	70R	Rack Down Specimens Mixed									Specimens Mixed		
60R	60R	65R	70R	70R	90R	90R												
0	0	0	0	0														
0	0	0	0															
96R	95R	95R	98R		Rack Down Specimens Mixed													
85R	85R	90R	90R	90R														
100Y	100Y	100Y	100Y	100Y			30R	30R	30R	50R	50R	50R	75R	70R	...			
							70Y		70Y	50Y	50Y	50Y	25Y	30nR	...			
TrR	TrR	15R	15R	15R			95R	95R	100R	X	X	X	X	X	...			
98Y	98Y	85Y	85Y	85Y														
X	X	X	X	X			X	X	X	X	X	X	X	X	...			

hoped that a more definitive summary of the performance of the various coatings can be presented when the next complete report on hardware is published.

Altoona, Pa.:[4]

(1) After an exposure of 12.8 yr., all specimens were completely rusted except those coated with aluminum, those coated with lead, and some of those coated with zinc. Rusting had started on all zinc- and most of the lead-coated pieces. The aluminum coatings were dark but free from rust. For greater detail, see Table VI. (2) All specimens were accidentally lost during a 1942 scrap salvage campaign.

Brunot Island (Pittsburgh), Pa.:[4]

(1) All specimens were stolen during the summer of 1939. (2) At the last inspection made (April, 1939) after an exposure of 10.3 yr., all specimens had rusted completely except those coated with aluminum, those coated with lead, and some of those coated with zinc. Rusting had started on all zinc- and lead-coated pieces. The aluminum coatings were dark but free from rust.

---

[4] A strict evaluation of the relative merits of the different types of metallic coatings should not be made from these observations without consideration of the rather wide spread in coating thicknesses.

State College, Pa.:[4]

After an exposure of 12.8 yr.: (1) complete rusting is confined largely to Parkerized and thin electrogalvanized, Sherardized, and cadmium coatings; (2) a few of the hot-dip zinc coatings show yellow alloy layer rust; (3) all aluminum-coated pieces are free from rust except at threaded areas where the threads had been recut due to roughness of coating; (4) the lead-coated specimens show definitely more rusting at this location than at the severe industrial locations. A few sets of lead-coated pieces are completely rusted. The rusting is in the form of pinhole spots generally scattered over most of the surface of each specimen. While these are unsightly, the coating must still be considered to have considerable protective value because deep-seated scale rusting has not appeared on any of these lead-coated specimens.

TABLE VII.—CORROSION CONDITIONS OF ZINC-COATED UNFABRICATED WIRES AFTER APPROXIMATELY SEVEN YEARS' EXPOSURE.

R = rust; Y = yellowed; G = gray; M = metallic; MG and GY = intermediate states.

Coating Group	Pittsburgh	Sandy Hook	Bridgeport	State College	Lafayette	Ames	Manhattan	Ithaca	Santa Cruz	College Station, Texas	Davis
0.20 to 0.30 oz. per sq. ft.	100R	100R	100R	100R	100R	49R	G	100R	G	28R	G
0.25 to 0.35 oz. per sq. ft.	100R	100R	100R	80R	100R	36R	G	76R	G	1R	G
0.35 to 0.45 oz. per sq. ft.	100R	100R	100R	10R	95R	1R	G	24R	G	GY	G
0.45 to 0.55 oz. per sq. ft.	100R	100R	100R	1R	11R	G	G	1R	G	1R	G
0.50 to 0.60 oz. per sq. ft.	100R	99R	100R	GY	1R	G	MG	G	MG	1R	MG
0.60 to 0.70 oz. per sq. ft.	100R	75R	80R	Y	G	G	MG	G	G	1R	G
0.70 to 0.85 oz. per sq. ft.	100R	70R	95R	GY	G	G	MG	G	MG	1R	MG
0.80 to 1.00 oz. per sq. ft.	100R	30R	25R	GY	G	G	MG	G	MG	1R	MG
1.20 to 1.35 oz. per sq. ft.	100R	GY	GY	GY	G	G	MG	MG	...	G	...
1.60 to 1.85 oz. per sq. ft.	100R	G	G	G	MG	G	MG	M	MG	G	MG
2.00 or more oz. per sq. ft.	G	G	G	G	MG	G	MG	M	MG	G	MG

Sandy Hook, N. J.:[4]

After an exposure of 12.8 yr.: (1) complete rusting has occurred on all Parkerized, cadmium plated, and some of the thinly coated electrogalvanized and Sherardized pieces; (2) several of the hot-dip zinc-coated pieces show rust; (3) a few of the aluminum-coated pieces show yellow rust, and these coatings permitted rusting also in areas of recut threads; (4) the lead-coated specimens show typical pinhole rusting to a greater extent than at the severe industrial locations. A few sets are completely rust-covered though for the most part not rusted to a scaling state, but there is an indication that this deep-seated rusting is starting on a few specimens at this location.

Key West, Fla.:[4]

After an exposure of 12.0 yr.: (1) complete rusting has occurred on all Parkerized and some of the thinly coated electrogalvanized, Sherardized, and cadmium-plated pieces; (2) most of the hot-dip galvanized pieces are free from rust, though a few sets show traces of rust; (3) about half of the sets of aluminum-coated pieces have rusted at this location although the surface area affected is small on most of the specimens involved; (4) the lead-coated specimens show pinhole rusting characteristics of this coating to a slightly greater extent than at the severe industrial locations, but less than at Sandy Hook. A few sets are completely rust covered.

EXPOSURE TESTS OF WIRE AND WIRE PRODUCTS

Semiannual inspections of the numerous specimens on exposure at Pittsburgh, Sandy Hook, Bridgeport, and State College were continued in 1943. The regular annual inspections at the university test plots were made by the resident university people. The findings from these visual inspections are summarized in Table VII.

During 1943 there were removed 174 tension specimens, as shown in Table VIII. The tension tests on these wires do not show any change in the rate of strength loss previously reported. No appreciable loss of strength was noted for any of the lead-coated specimens. Analyses made on lead coatings during the year have indicated that the bonding layer observable in the previously published photomicrographs may be a zinc coating inasmuch as the analyses showed the coatings to contain zinc. The analytical data have been reported as an addendum to the 1943 Report of Committee A-5.[5]

TABLE VIII.—NUMBER OF WIRE SPECIMENS REMOVED FOR TENSION TESTS.

Location	Number of Wires Removed in 1943				Wires Removed Prior to 1941	Total Removed to Date
	Bare Steel	Zinc Coated	Lead Coated	Corrosion Resistant		
Pittsburgh	4	75	4	0	405	488
Sandy Hook	11	36	0	0	148	195
Bridgeport	0	30	4	0	130	164
State College	0	6	4	0	52	62
All other locations	0	0	0	0	282	282
Total	15	147	12	0	1017	1191

In addition to the above removals, one set (36 wires) of weight loss specimens was removed from State College. The data on these wires confirmed the previously reported annual weight loss of 0.06 oz. per sq. ft. at this test site.

This report has been submitted to letter ballot of Subcommittee VIII which consists of 64 members; 48 members returned their ballots, of whom 47 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the subcommittee,

C. E. REINHARD,
Chairman.

---

[5] *Proceedings*, Am. Soc. Testing Mats., Vol. 43, p. 78 (1943).

APPENDIX

PROPOSED SPECIFICATIONS FOR LEAD-ALLOY (HOT-DIP) COATED STEEL SHEETS[1]

These are proposed specifications and are published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 260 S. Broad St., Philadelphia 2, Pa.

Scope

1. These specifications cover steel sheets, lead-alloy coated by the hot-dip process. No weight of coating is specified (Note) as these specifications cover sheets with commercial coatings for general utility.

NOTE.—Due to the present status of the art of applying hot-dipped lead-alloy coatings, the committee responsible for these specifications has not found it practicable at present to list weights of coating. If minimum weight of coating by a sheet weight test is desired it should be subject to negotiation between the manufacturer and the purchaser.

Interpretation of Numerical Requirements

2. The numerical requirements of these specifications are subject to the interpretations set forth in the Tentative Recommended Practices for Designation of Numerical Requirements in Standards (A.S.T.M. Designation: E 29).[2] Particular attention is called to the use of the phrase "to the nearest . . . " in expressing specified limits.

Base Metal Manufacture

3. The base metal shall be made by the acid-bessemer or basic open-hearth process.

Base Metal Chemical Composition

4. No requirements for chemical composition of the base metal are specified except that when a copper content is ordered it shall conform to the following requirements:

Copper, min., per cent (to the nearest 0.01 per cent):	
Ladle analysis	0.20
Check analysis	0.18

Base Metal Check Analysis

5. A check analysis may be made by the purchaser, using drillings or millings from the test specimens specified in Section 9 after removal of the lead coating. The copper content thus determined shall conform to the requirements specified in Section 4.

Lead for Coating

6. The lead used for the coating may be secondary metal, or reclaimed lead, containing not more than 2.5 per cent tin (tin shall be determined to the nearest 0.1 per cent).

Base Metal Bend Tests

7. The bend test specimen specified in Section 9 shall stand being bent cold through 180 deg. in either direction without fracture of the base metal. Sheet metal lighter than No. 16 gage shall be bent flat on itself, and No. 16 gage and heavier shall be bent over one thickness of the specimen tested. A vise with smooth jaws and operated by hand shall be used for making the bend tests.

---

[1] These proposed specifications are under the jurisdiction of the A.S.T.M. Committee A-5 on Corrosion of Iron and Steel. Published as information, June, 1944.

[2] 1944 Book of A.S.T.M. Standards, Part I.

Coating Bend Tests

8. The bend test specimen specified in Section 9 shall stand being bent cold through 180 deg. in either direction without flaking or cracking of the coating on the specimen. Sheet metal lighter than No. 16 gage shall be bent flat on itself and No. 16 gage and heavier shall be bent over one thickness of the specimen tested. A vise with smooth jaws and operated by hand shall be used for making the bend tests.

TABLE I.—LEAD-ALLOY COATED SHEET GAGE.

Lead-Alloy Coated Sheet Gage Number	Weight of Coating		
	oz per sq. ft.	lb per sq. ft.	lb per sq in.
8	112.5	7.0312	0.048828
9	102.5	6.4062	0.044488
10	92.5	5.7812	0.040148
11	82.5	5.1562	0.035807
12	72.5	4.5312	0.031467
13	62.5	3.9062	0.027127
14	52.5	3.2812	0.022786
15	47.5	2.9688	0.020616
16	42.5	2.6562	0.018446
17	38.5	2.4062	0.016710
18	34.5	2.1562	0.014974
19	30.5	1.9062	0.013238
20	26.5	1.6562	0.011502
21	24.5	1.5312	0.010634
22	22.5	1.4062	0.0097656
23	20.5	1.2812	0.0088976
24	18.5	1.1562	0.0080295
25	16.5	1.0312	0.0071615
26	14.5	0.90625	0.0062934
27	13.5	0.84375	0.0058594
28	12.5	0.78125	0.0054253
29	11.5	0.71875	0.0049913
30	10.5	0.65625	0.0045573
31	9.5	0.59375	0.0041233
32	9.0	0.56250	0.0039062
33	8.5	0.53125	0.0036892
34	8.0	0.50000	0.0034722

Test Specimens

9. Bend test specimens 3 to 4 in. in width shall be cut from the test sheet within an area formed by lines 2 in. from the sides and 4 in. from the ends of the sheet. Test specimens, so far as practicable, shall be cut from sheets that are imperfect in areas other than those from which the specimens are selected.

Number of Tests

10. The bend tests shall be made on specimens from one sheet in each lot of 1000 sheets or fraction thereof of each gage. If the sheet fails to conform to the bend test requirements prescribed in Sections 7 and 8, retest shall be made from two other sheets in the same lot and if either of these sheets fails to conform to the requirements the lot shall be rejected.

Permissible Variations in Weight

11. Gage weights shall not vary from those in Table I by more than the limits shown in Table II calculated to the nearest fifth significant figure on the basis of the ordered size.

TABLE II.—PERMISSIBLE VARIATIONS FROM ORDERED GAGE WEIGHT FOR ALL OF ONE GAGE AND SIZE.

Ordered Lead-Alloy Coated Sheet Gage	Variations from Ordered Gage Weight,[a] per cent[b]			
	20 tons or over	Under 20 tons to 3 tons, incl.	Under 3 tons to 1 ton, incl.	Under 1 ton
No. 18 and heavier	3.5	5.0	7.5	10.0
No. 19 and lighter	2.5	3.0	5.0	10.0

[a] The tonnage ordered for shipment to one place at one time determines the permissible variation for that tonnage. Any partial shipment against that tonnage shall not vary more than the amount given in the above table for the lesser amount.

[b] For sheets 72 in. and over in width, add 2 per cent to the amounts shown in the table.

Permissible Variations in Dimensions, Sheets not Ordered Resquared

12. (*a*) *Width.*—Sheets not ordered resquared shall not exceed the permissible variations in width shown in the following table:

Ordered Width, in.	Permissible Variation Over Ordered Width,[a] in. (to the nearest $\frac{1}{16}$ in.)
2 and under	$\frac{1}{16}$
Over 2 to 6, incl.	$\frac{1}{8}$
Over 6 to 15, incl.	$\frac{1}{8}$
Over 15 to 20, incl.	$\frac{1}{8}$
Over 20 to 30, incl.	$\frac{3}{16}$
Over 30 to 50, incl.	$\frac{1}{4}$
Over 50 to 80, incl.	$\frac{5}{16}$
Over 80	$\frac{3}{8}$

---

[a] No variation under the ordered width shall be permissible.

(*b*) *Length.*—Sheets not ordered resquared shall not exceed the permissible variations in length shown in the following table:

Ordered Length, in.	Permissible Variation Over Ordered Length, in. (to the nearest $\frac{1}{8}$ in.)
15 and under	$\frac{1}{8}$
Over 15 to 30, incl.	$\frac{1}{4}$
Over 30 to 60, incl.	$\frac{1}{2}$
Over 60 to 96, incl.	$\frac{3}{4}$
Over 96 to 120, incl.	1
Over 120 to 156, incl.	$1\frac{1}{4}$
Over 156 to 192, incl.	$1\frac{1}{2}$
Over 192 to 240, incl.	$1\frac{3}{4}$
Over 240	2

(*c*) *Out-of-Square.*—Sheets not resquared shall not be out-of-square more than $\frac{1}{16}$ in. per 6 in. or fraction thereof of the specified width measured along an edge. Out-of-square is the greatest deviation (to the nearest $\frac{1}{16}$ in.) of an end edge from a straight line at right-angle to a side and touching one corner.

(*d*) *Camber.*—For sheets not resquared the camber shall not exceed the limits shown in the following table:

Ordered Length, in.	Camber,[a] in. (to the nearest $\frac{1}{16}$ in.)
4 and under	$\frac{1}{8}$
Over 4 to 6, incl.	$\frac{3}{16}$
Over 6 to 8, incl.	$\frac{1}{4}$
Over 8 to 10, incl.	$\frac{5}{16}$
Over 10 to 12, incl.	$\frac{3}{8}$
Over 12 to 14, incl.	$\frac{1}{2}$
Over 14 to 16, incl.	$\frac{5}{8}$
Over 16 to 18, incl.	$\frac{3}{4}$
Over 18 to 20, incl.	$\frac{7}{8}$
Over 20 to 30, incl.	$1\frac{1}{4}$
Over 30 to 40, incl.	$1\frac{1}{2}$

[a] Camber is the greatest deviation of a side edge from a straight line touching both ends of the side.

Permissible Variations in Dimensions, Sheets Ordered Resquared

13. When sheets are ordered resquared, the width and length shall be not less than ordered; over-width, over-length, out-of-square, and camber, measured to the nearest $\frac{1}{32}$ in., shall not be more than $\frac{1}{16}$ in. for sheets 48 in. and under in width or 120 in. in length; or $\frac{1}{8}$ in. for wider or longer sheets. When sheets are ordered resquared before coating double these variations shall be permissible.

Permissible Over-Size Sheets Ordered for Reshearing

14. When sheets are ordered for reshearing by the purchaser, the over size shall be $\frac{1}{8}$ in. for each additional intended cut in addition to the variations prescribed in Sections 12 and 13.

Finish

15. The sheets shall be of prime finish, that is, free from injurious defects, such as flux spots and uncoated areas visible to the naked eye. Irridescent appearance or presence of discoloration does not affect the quality of the lead coating and is, therefore, not considered a defect for purpose of rejection.

Marking

16. The top sheet of each bundle or the top sheet of a number of sheets when shipped loose shall, unless otherwise ordered, show legibly the name and brand of the manufacturer, gage, and size.

Inspection

17. The inspector representing the purchaser shall have free entry at all times, while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works which concern the manufacture of the material ordered. The manufacturer shall afford the inspector all reasonable facilities, without charge, to satisfy him that the material is being furnished in accordance with these specifications. All tests (except check analyses) and inspection shall be made at the place of manufacture prior to shipment, unless otherwise specified, and shall be so conducted as not to interfere unnecessarily with the operation of the works.

Rejection

18. If the purchaser elects to test and inspect the material at its destination, sheets represented by specimens that fail to conform to the requirements of these specifications will be rejected and the manufacturer shall be notified within two weeks from receipt of shipment by the purchaser.

Rehearing

19. Sheets and specimens tested in accordance with Sections 7 and 8 that represent rejected material shall be preserved for two weeks from the date of notification to the manufacturer. In case of dissatisfaction with the results of the test the manufacturer may require a rehearing within that time.

REPORT OF COMMITTEE A-6
ON
MAGNETIC PROPERTIES

Two meetings of Committee A-6 on Magnetic Properties have been held during the past year, together with several subcommittee meetings.

In view of the fact that a new edition of the Book of A.S.T.M. Standards is to be published this year, it is proposed to recommend the adoption as standard of the tentative standards under the jurisdiction of the committee, which have been available less than a year. It is felt that this is justified since there have been no important changes suggested. Moreover, these methods are coming into general use.

Since most laminated cores for electrical apparatus operate at maximum inductions nearer 15 kilogausses than 10 kilogausses, the A-6 methods of test are being changed to give equal emphasis to the higher induction test, with the thought that when industry gets used to it, the higher induction test will probably become the preferable one. This procedure has the approval of the American Institute of Electrical Engineers and the National Electrical Manufacturers Assn. It will be necessary for the electrical steel manufacturers to develop new core loss limits for the various standard grades of sheet corresponding to the 15 kilogauss induction. This will take some time, since the conversion factors from 10 to 15 kilogausses vary with the thickness of the material and the condition of the surface as well as the physical structure and chemical composition of the various grades. The adoption of the higher induction may result in improvements in standard grades as applied to commercial apparatus, since a material which is poorer than average in core loss at 10 kilogausses may be better than average at 15 kilogausses. A summary prepared by J. P. Barton and B. M. Smith of comparison core loss tests on Epstein samples for various inductions is given in the Appendix. It was on the basis of these tests that Committee A-6 felt that it was feasible to specify the 15-kilogauss test as an alternate to the 10-kilogauss test for use by commercial magnetic testing laboratories. A study of the data will make clear why certain precautions are necessary for the higher induction testing.

At a recent meeting of Committee A-6 there was some discussion of the desirability of developing a standard form for preparing specifications for electrical sheet. At present different companies have widely varying specifications for similar material and there is often a considerable variation in form among the different electrical sheet specifications put out by a single company. There is no intention at present to specify standard limits for the various grades of steel, but it is hoped that better uniformity of arrangement and scope of properties covered may be attained in electrical sheet specifications if a standard guide is available.

The present officers and members of

the executive committee have been reelected for the ensuing term of two years.

Subsequent to the Annual Meeting, Committee A-6 presented to the Society through Committee E-10 on Standards the following recommendations:

Revision of Tentative Methods of:

Test for Permeability and Core Loss of Flat-Rolled Magnetic Materials Using 28-cm. Specimen (A 257 – 42 T),
Test for Incremental Permeability and Core Loss of Flat-Rolled Magnetic Materials at Low Alternating Inductions Using 28-cm. Specimen (A 258 – 42 T),
Test for Permeability of Feebly Magnetic Materials (A 259 – 42 T), and

Tentative Revision of Standard Methods of:

Test for Magnetic Properties of Iron and Steel (A 34 – 42).

These recommendations were accepted[1] by Committee E-10 on August 30, 1943, and the revised tentative standards and the tentative revision appear in the 1943 Supplement to the Book of A.S.T.M. Standards, Part I.

I. NEW TENTATIVE STANDARD

The committee recommends that the proposed Definitions of Terms, With Symbols, Relating to Magnetic Testing[2] be accepted for publication as tentative, to replace the Standard Definitions of Terms, with Units and Symbols, Relating to Magnetic Testing (A 127 – 41)[3] and the tentative revisions[4] of these definitions published in June, 1943.

II. ADOPTION OF TENTATIVE STANDARDS AS STANDARD

The committee recommends that the following tentative methods of test be approved for reference to letter ballot of the Society for adoption as standard without revision:

Tentative Methods of Test for:

Permeability and Core Loss of Flat-Rolled Magnetic Materials Using 28-cm. Specimen (A 257 – 43 T),
Normal and Incremental Permeability and Core Loss of Flat-Rolled Magnetic Materials at Low Alternating Inductions Using 28-cm. Specimen (A 258 – 43 T), and
Permeability of Feebly Magnetic Materials (A 259 – 43 T).

It is also recommended that upon adoption these three methods be incorporated in the Standard Methods of Test for Magnetic Properties of Iron and Steel (A 34 – 42).

III. REVISION OF STANDARD, IMMEDIATE ADOPTION

The committee recommends for immediate adoption, the following revisions in the Standard Methods of Test for Magnetic Properties of Iron and Steel (A 34 – 42)[5] and accordingly asks for the necessary nine-tenths vote at the Annual Meeting in order that these modifications may be referred to letter ballot of the Society:

Section 2.—In place of the definitions in this section substitute a reference to the new Tentative Definitions of Terms, with Symbols, Relating to Magnetic Testing.[2]

Section 6 (b).—At the end of the sentence change "10 kilogausses" to read "10 or 15 kilogausses."

Section 9.—In the first sentence in Paragraph *(a)*, change "magnetizing winding" to read "magnetizing (primary) winding." In the second sentence, change "secondary coil" to read "potential (secondary) winding," insert "average" before the word "voltmeter," insert "the rms. voltmeter" after the word "voltmeter," and change "potential coil" to read "voltage circuit."

---

[1] In submitting these recommendations to Committee E-10 on Standards, Committee A-6 reported the following results of the letter ballot vote from a committee membership of 23: A 257, A 258, A 259, and A 34, affirmative 14, negative 0, ballots marked "not voting" 0.

[2] These definitions were accepted as tentative by the Society and appear in the 1944 Book of A.S.T.M. Standards, Part I, p. 1437.

[3] 1942 Book of A.S.T.M. Standards, Part I.

[4] 1943 Supplement to Book of A.S.T.M. Standards, Part I.

[5] 1943 Supplement to Book of A.S.T.M. Standards, Part I.

In the first sentence in Paragraph (*c*), change "a voltmeter" to read "an average voltmeter, a rms. voltmeter," and change "voltage coil" to read "voltage circuit." In the second sentence, change "coil" to read "circuit."

Fig. 3.—At the end of Section 9, add as a new Fig. 3 the circuit diagram shown in the accompanying Fig. 1, renumbering the subsequent figures accordingly.

Section 10 (*c*).—Change from its present form: namely,

> (*c*) If desired, a 5-kg. specimen may be used at 10 kilogausses, provided it is cut from at least two sheets. Tests on the 5-kg. specimen at 15 kilogausses may be made, provided the test apparatus has solenoids of suitable cross-sectional area and standard windings so that there need be no correction for air flux. For this the dimensions of the winding form shall be, inside cross-section 1.9 by 3.8 cm., thickness of wall not over 0.3 cm., and winding length 42 cm. All other specifications remain the same as for the 10-kg. specimen.
>
> NOTE.—If desired, for convenience, the bundles may be loosely secured by tape or string (not wire).

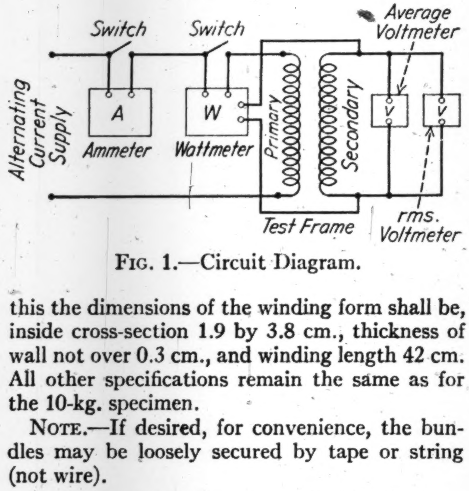


FIG. 1.—Circuit Diagram.

to read as follows, retaining the present note:

> (*c*) If desired, a 5-kg. specimen may be used at 10 and 15 kilogausses, provided it is cut from at least two sheets. The tests at these two flux densities are to be made using a test frame, the winding form dimension of which shall be:
>
> Inside cross-section . . . . 1.9 by 3.8 cm.
> Thickness of wall . . . . not over 0.3 cm.
> Winding length . . . . 42 cm.
>
> All other specifications remain the same as for the 10-kg. specimen. The change in winding form dimensions is required to eliminate the need for air flux correction at 15 kilogausses.

Section 11.—Add a new Paragraph (*a*) to read as follows, relettering the subsequent paragraphs accordingly:

> (*a*) The temperature of the test specimen shall be 25 ± 5 C. Unless otherwise specified, 10 and 15 kilogausses shall be the standard maximum inductions, with the frequency to be 60 cycles per second. The standard core loss shall be represented by the symbol $P_{10/60}$ and $P_{15/60}$.

Reletter the present Paragraph (*a*) as (*b*), and change the second sentence to read as follows: "No insulation shall be used between laminations other than that present on the surface of the sheet at the time the test specimen strips are cut, but the corner joints may be separated by tough paper approximately 0.1 mm. (0.004 in.) in thickness."

Reletter the present Paragraph (*b*) as (*c*), and in the equation for E, change "4*ff*" to read "4.44," and delete the definition "*ff*" = form factor of primary emf. = 1.11 for sine wave." Change the definitions for B and E to read as follows and delete Note 2:

> B = maximum induction in kilogausses = 10 or 15 kilogausses.
>
> E = 106.6 v. for 10 kilogausses and 160.0 for 15 kilogausses for high resistance silicon steel for sine voltage; 103.8 v. for 10 kilogausses and 155.8 v. for 15 kilogausses for low resistance silicon steel for sine voltage.

Change Paragraph (*c*) from its present form: namely,

> (*c*) For the 15-kilogauss tests and whenever the form factor of the applied electromotive force varies more than 1 per cent from the value of 1.11, an average voltage instrument shall be used in multiple with the rms. voltmeter. For convenience, the average voltmeter scale may be marked in terms of average volts times 1.11. The calculated rms. voltage as given above is then held on the average voltmeter.

to read as follows, retaining present Notes 3 and 4:

> (*d*) For the 10- and 15-kilogauss tests, an average voltage instrument shall be used to indicate the rms. voltage as calculated in Section

11 (*b*). For convenience, the average voltmeter shall be marked in terms of average volts times 1.11. The rms. voltmeter shall be connected in parallel with the average voltmeter, to determine the instrument losses and the form factor of the applied voltage.

Reletter Paragraph (*i*) as (*j*) and in the first sentence insert "average" before the word "voltmeter."

Reletter Paragraph (*j*) as (*k*) and change to read as follows: "When the voltage and frequency are correct, the wattmeter and the rms. voltmeter shall be read."

Section 12.—Change the definition for R to read: "R = parallel resistance of the average voltmeter, the rms. voltmeter and the shunt (voltage) circuit of the wattmeter."

Change Note 1 to read as follows:

NOTE 1.—The form factor of the applied voltage may be determined from the rms. and the average voltmeter readings, as follows:

$$\text{Form factor} = \frac{\text{rms. voltmeter reading}}{\text{average voltmeter reading}} \times 1.11$$

In Note 2, change "windings" to read "circuits."

Section 24 (*b*).—Indicate the present note as Note 1 and add the following as Note 2.

NOTE 2.—It is recognized in Section 24 (*a*) and (*b*) that the test strips are cut from sheet or strip material which, as received from the manufacturer, may be in the pickled last condition, oxide coated or insulated. Further preparation of the test specimens can be made by the purchaser, such as annealing, insulating, or any combination of the two treatments, depending upon how the purchaser processes his laminations and his desire to more closely approach his lamination production in testing interlamination resistance. In such cases, this test then becomes one of quality control for the purchaser's plant only, as it is essentially impossible for the manufacturer to duplicate the purchaser's further preparation of the test specimens over that covered in Section 24 (*a*) and (*b*).

Section 25.—Add the following note at the end of Paragraph (*e*):

NOTE.—In evaluating the results of this test, it must be observed that a reshuffling of the test strips and retesting will usually give a new value for the resistance. Also that a number of specimens from the same lot of sheets or strips will yield variations in interlamination resistance as much as 10 to 1. Therefore in setting minimum values for control purposes, a large number of specimens should be prepared from different lots of the same material, and the results analyzed statistically. It should further be observed that in any laminated core structure, it is desirable to maintain the interlamination resistance well above (5 or more times) the threshold value that will give rise to troublesome stray losses, recognizing the variations in interlamination resistance in the core structure as illustrated by the standard test at the pressures involved.

It may be pointed out that if the test specimens are annealed and/or insulated after shearing or punching, a considerable increase in interlamination resistance will be obtained in general. Also very low values will generally be obtained on a material which is pickled last without further treatment.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. NEW TENTATIVE STANDARD			
Def. of Terms, With Symbols, Relating to Magnetic Testing, to replace Standard Definitions A 127	16	0	0
II. ADOPTION OF TENTATIVE STANDARDS AS STANDARD			
Test for Permeability and Core Loss of Flat-Rolled Magnetic Materials Using 28-cm. Specimen (A 257 - 43 T)	16	0	0
Test for Normal and Incremental Permeability and Core Loss of Flat-Rolled Magnetic Materials at Low Alternating Inductions Using 28-cm. Specimen (A 258 - 43 T)	16	0	0
Test for Permeability of Feebly Magnetic Materials (A 259 - 43 T)	16	0	0
III. REVISION OF STANDARD, IMMEDIATE ADOPTION			
Test for Magnetic Properties of Iron and Steel (A 34 - 42)	16	0	0

The committee also recommends that the tentative revision[5] in Methods A 34 submitted last year, which provides for a change in Section 10 (*a*) and the addition of a note to Section 12, be adopted as standard this year and included along with the other revisions listed above.

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 24 members; 16 members returned their ballots, with the results shown in Table I.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Nomenclature and Definitions (P. H. Dike, chairman).—The need for revision of definitions of terms used in magnetic testing, together with suitable letter symbols has been felt for some time, as mentioned in the previous annual report. It was believed that magneticians should have available definitions which are clearly stated in general terms not requiring a knowledge of higher mathematics. Some of the definitions in the American Standard Definitions of Electrical Terms (ASA C 42 - 1941), as published by the American Institute of Electrical Engineers, do not meet these requirements. Some of the definitions in the present A.S.T.M. Standard Definitions of Terms, with Units and Symbols, Relating to Magnetic Testing (A 127 - 41), which were based on the American Standard definitions, are subject to the same criticism. Also there are some inaccuracies in the American Standard definitions. Several meetings of this subcommittee have been held during the year as a result of which proposed new Definitions of Terms, with Symbols, Relating to Magnetic Testing[2] are being recommended for publication as tentative to replace Standard Definitions A 127 as well as the tentative revisions issued in 1943. If some of these definitions should seem to the theoretical scientist to be loose or inadequate, it must be remembered that rigorous scientific accuracy has sometimes been sacrificed for the sake of conveying the idea to the technician in nonmathematical language.

So far as feasible, the suggested letter symbols are in accord with latest ASA recommendations. However, in some instances, it was felt necessary to depart from such recommendations.

It has been decided to eliminate the definitions at the beginning of Methods A 34 - 42, since they are included in the new glossary of magnetic definitions.

Subcommittee III on Direct Current Test Methods (B. M. Smith, chairman).—As mentioned earlier in this report, it was found possible, by action through Committee E-10 on Standards, to include in the 1943 Supplement to the Book of A.S.T.M. Standards a third method for testing feebly magnetic materials (A 259 - 43 T). This method was developed by the Leeds and Northrup Co. and, for certain applications, has advantages over the other two proposed standard methods.

Work is continuing on the proposal to use the 25-cm. frame with double lap joint for d-c. permeability measurements on laminated materials. The results to date look promising. For the high magnetizing forces some form of permeameter will still be required.

Subcommittee IV on Alternating Current Test Methods (J. P. Barton, chairman).—As suggested in last year's report, the Tentative Method of Test for Incremental Permeability and Core Loss of Flat-Rolled Magnetic Materials at Low Alternating Inductions Using 25-cm. Specimens (A 258 - 42 T) was combined with Sections 13 to 21, inclusive, of the Standard Methods of Test for Magnetic Properties of Iron and Steel (A 34 - 42) and issued as Tentative Method A 258 - 43 T. This tentative method of test is now being recommended for adoption as standard since no unfavorable comments have been received, and that it be incorporated in Methods A 34.

With reference to the investigation of methods of measuring core losses up to 10,000 cycles, as proposed in the 1943 report, progress can be reported. Round-robin tests are being made on 0.007 and 0.014-in. thick electrical sheet, both cold-reduced and hot-rolled material. The American Rolling Mill Co. and the Carnegie-Illinois Steel Corp. have submitted results with moderately good agreement. At least two other laboratories will test these samples before an attempt is made to formulate a standard test procedure. The properties of electrical sheet at higher frequencies are becoming increasingly important, particularly with reference to induction heating applications and aviation.

This report has been submitted to letter ballot of the committee which consists of 24 members; 16 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

THOMAS SPOONER,
Chairman.

R. L. SANFORD,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting Committee A-6 presented to the Society through Committee E-10 on Standards a proposed tentative revision of the Standard Methods of Test for Magnetic Properties of Iron and Steel (A 34 – 44). This recommendation was accepted by the Standards Committee on September 15, 1944, and the tentative revision appears in the 1944 Book of A.S.T.M. Standards, Part I, p. 2003.

REPORT ON ROUND-ROBIN CORE LOSS TESTING AT HIGH FLUX DENSITIES

SUBMITTED BY CHAIRMEN OF SUBCOMMITTEES III AND IV

Committee A-6 on Magnetic Properties recognized in late 1934 the fact that testing at 14 kilogausses did not adequately evaluate the core loss characteristics as well as would tests made at 15 kilogausses or higher, as rotating machinery designs were continuing to use silicon steel at higher flux densities. It was decided to prepare seven Epstein specimens from material of different silicon contents for round-robin testing by the laboratories of several producers and consumers in the flux density range of 10 to 16 kilogausses at 60 cycles, under several conditions of measuring the voltage and making corrections in the core loss. This report is a summary of these tests and the resulting conclusions which led to the adoption in 1936 of a core loss test at 15 kilogausses now included as an alternate procedure in the Standard Methods of Test for Magnetic Properties of Iron and Steel (A 34 – 42).[1]

During the past 30 yr., the reduction in core loss in silicon steel and the design of electrical machinery operating at higher flux densities, has gradually continued, resulting in a need for core loss testing at flux densities higher than 10 kilogausses. For some time, 14 kilogausses were used but investigations[2] in the early 30's showed that the routine testing procedure in effect up to 1934 was inadequate at higher flux densities. It was also observed that in some materials a sample X may have a lower core loss than sample Y at 10 kilogausses but have a higher core loss at 15 kilogausses.

The chief difficulty in testing at flux densities over 13 kilogausses is the large increase in magnetizing force which causes a distortion of the flux wave, gives a large air flux in the test coil, and reduces the power factor to a very low value. The distortion of the flux wave is usually due to inadequate source of power to supply the low power factor kilovolt-amperes necessary to maintain a sine flux wave, as well as the impedance of circuit elements not being as low as desirable. Thus, if an rms. voltmeter is used across the secondary of the Epstein test frame, to indicate the rms. voltage, generated by non-sine wave flux, the maximum flux density will usually depart from the value chosen at which to test the core loss. A distorted flux wave also introduces additional losses due to high-frequency components of the eddy currents. The error in the measurement of maximum flux B_m is eliminated by measuring the secondary voltage with an average voltmeter as the value of the average voltage depends on the maximum value of the flux, irrespective of the form of the wave. When B_m is correctly determined, the hysteresis component of the loss is also correct. The error in measurement is in the eddy current component, which is usually between 20 to 40 per cent of the total core loss. This error can be corrected by the percentage eddy current method[1] and involves the form factor, which is readily computed from readings taken simultaneously on the rms. and average voltmeters in parallel across the secondary winding of the Epstein test frame.

---

[1] 1942 Book of A.S.T.M. Standards, Part I, p. 651.

[2] B. M. Smith and C. Concordia, "Core Loss Measurements at High Flux Densities," *Electrical Engineering*, Am. Inst. Electrical Engineers, Vol. 51, No. 1, January, 1932.

The air flux enclosed by the test coil outside the test specimen produces a voltage which should be considered in calculating the desired induced voltage. At low densities the air flux is negligible but at high densities it should be included due to the high magnetizing forces. The low power factor encountered in testing emphasizes the small phase angle error inherent in the wattmeters, which should be of the low power factor type and of large current capacity. The non-uniformity of flux distribution over the length of the test specimens is no greater at high densities than it is at medium flux densities.

Considering these factors, a schedule to tests was established in which each specimen was measured for core loss in fhe flux density range of 10 to 16 kilogausses at 60 cycles, setting the secondary voltage with the following:

Test 1. An rms. voltmeter,
Test 2. An average voltmeter,
Test 3. An average voltmeter and correcting the voltage for the air flux,
Test 4. An average voltmeter and correcting the core loss by the eddy current method, and
Test 5. An average voltmeter, and correcting the voltage for the air flux, and the core loss by the eddy current method.

The following laboratories participated in the tests:

American Rolling Mill Co.,
Bell Telephone Laboratories, Inc.
Carnegie-Illinois Steel Corp.,
General Electric Co.,
National Bureau of Standards, and
Westinghouse Electric and Manufacturing Co. (two laboratories)

In all cases, both the rms. and the average voltmeters were in parallel and were read simultaneously for determining the form factor. The average voltmeter accompanied the test specimens and the regular test equipment was used in each laboratory. This voltmeter had a resistance of 1000 ohms per v. with the full wave rectifier using small copper oxide units.

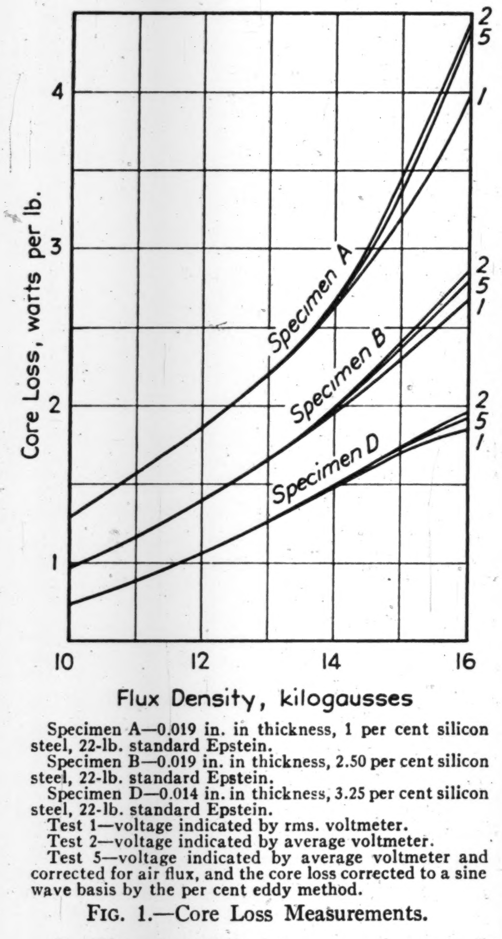
The test specimens were all 22 lb. standard Epstein specimens 3 by 50 cm., as follows:

Specimen	Thickness, in.	Silicon Content, per cent
A	0.019	1.00
B	0.019	2.50
C	0.014	2.50
D	0.014	3.25
E	0.014	4.50
F	0.019	2.50
G	0.011[a]	3.00[b]

[a] Cold reduced.
[b] Oriented grain.

The results of the tests are shown in Figs. 1 and 2, but curves from tests 1, 2, and 5 are shown with tests 3 and 4 being omitted for the following reasons: The air flux correction (test 3) increases the core loss over that for test 2, while the correction for core loss by the eddy current method (test 4) usually decreases the core loss under that for test 2. The curves for tests 3 and 4 would obscure the curves for tests 1, 2, and 5, and these corrections are included in test 5.

The test data were averaged and the curves of Figs. 1 and 2 were drawn. The degree of agreement between the various laboratories was considered good over the flux density range of 10 to 16 kilogausses, the variation from the average values ranging up to plus or minus 2 per cent with about 10 per cent of the test values showing greater deviations, and at random. It will be observed that up to about 13 kilogausses, the core loss is the same for both the rms. and the flux voltmeters. Above 13 kilogausses, the differences in core loss *versus* voltmeter used to set the voltage, increase rapidly, plainly illustrating the errors in core loss measurement when the rms. voltmeter is used.



Specimen A—0.019 in. in thickness, 1 per cent silicon steel, 22-lb. standard Epstein.
Specimen B—0.019 in. in thickness, 2.50 per cent silicon steel, 22-lb. standard Epstein.
Specimen D—0.014 in. in thickness, 3.25 per cent silicon steel, 22-lb. standard Epstein.
Test 1—voltage indicated by rms. voltmeter.
Test 2—voltage indicated by average voltmeter.
Test 5—voltage indicated by average voltmeter and corrected for air flux, and the core loss corrected to a sine wave basis by the per cent eddy method.

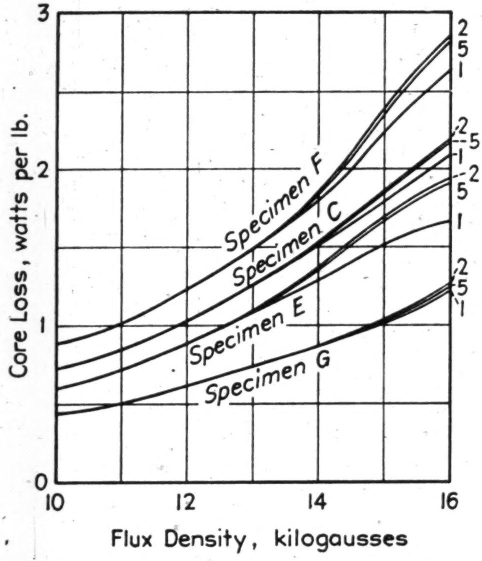
FIG. 1.—Core Loss Measurements.

In Figs. 1 and 2 the curves for test 5 show test 2 corrected for air flux and eddy current loss. Inasmuch as these two corrections tend to balance each other, with the eddy current correction being the larger, test 5 at 15 kilogausses is 1.50 to 1.75 per cent lower than test 2, depending on the sample; at 16 kilogausses, the range is about 1 to 3 per cent.

Conclusions:

As a result of this round-robin test and general experience of the testing laboratories, 15 kilogausses were chosen as the test flux density for the following reasons:

1. In general, the magnetizing force for 16 kilogausses is twice that for 15 kilogausses, thus requiring approximately twice the kilovolt-amperes and thereby tending to increase the wave form distortion and doubling the current carrying requirements of the wattmeter, exceeding in some cases the capacity of commercial meters.



Specimen C—0.014 in. in thickness, 2.5 per cent silicon steel, 22-lb. standard Epstein.
Specimen E—0.014 in. in thickness, 4.5 per cent silicon steel, 22-lb. standard Epstein.
Specimen F—0.019 in. in thickness, 2.5 per cent silicon steel, 22-lb. standard Epstein.
Specimen G—0.011 in. in thickness, 3.0 per cent silicon steel, 22-lb. standard Epstein, cold reduced, oriented grain structure.
Test 1—voltage indicated by rms. voltmeter.
Test 2—voltage indicated by average voltmeter.
Test 5—voltage indicated by average voltmeter and corrected for air flux, and the core loss corrected to a sine wave basis by the per cent eddy method.

FIG. 2.—Core Loss Measurements.

2. At 15 kilogausses, the average difference between test 2 and test 5 is about 1 per cent, thus making it possible to dispense with the correction factors for

air flux and eddy current loss, and set the test voltage with the average voltmeter only, considerably simplifying routine testing. This simplified procedure should not be followed at 16 kilogausses or higher densities as the correction factors must then be applied.

3. Testing at 14 kilogausses does not readily show the trend of the core loss curve as well as tests at 15 kilogausses. Also, in view of the cross-over effect previously mentioned of a sample X having a lower core loss than sample Y, at 10 kilogausses but having a higher loss at 15 kilogausses, the testing at 14 kilogausses would not as readily disclose this feature as would testing at higher flux densities.

4. Fifteen kilogausses is within the range of densities used for rotating machines and is adequate in rating the core loss of materials operating in the vicinity of this flux density. This density is particularly suited for testing silicon steels having highly directional magnetic properties (oriented grain structure).

In view of these conclusions, 15 kilogausses were chosen for the core loss test when needed at flux densities higher than 10 kilogausses, requiring only the average voltmeter as the additional equipment for indicating the voltage for that flux density. For the use of an 11-lb. test specimen, a winding form of a smaller cross-sectional area was specified to maintain the air flux at about the same value as for the 22-lb. test frame. These requirements were incorporated in the core loss section of Standard Method A 34 in 1936.

In view of increased interest in core losses at 15 kilogausses, it is recommended that both 10 and 15 kilogausses be recognized as standard test densities and that the test procedures of the core loss section of Method A 34 be modified accordingly.

Respectfully submitted on behalf of Subcommittees III and IV,

J. P. BARTON,
Chairman, Subcommittee IV.
B. M. SMITH,
Chairman, Subcommittee III.

REPORT OF COMMITTEE A-7

ON

MALLEABLE-IRON CASTINGS

Committee A-7 on Malleable-Iron Castings met in Cincinnati, Ohio, on February 28, 1944.

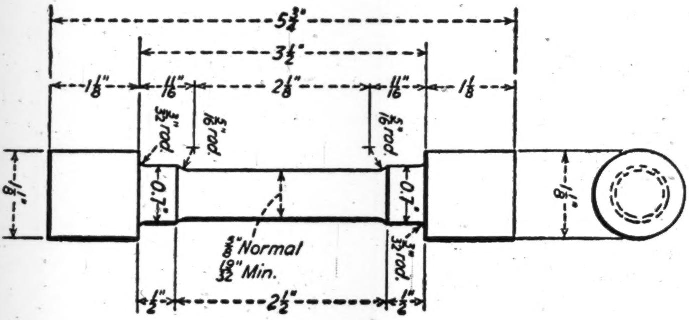
The committee records with sorrow the death of Enrique Touceda, a member of Committee A-7 since its organization in 1918 and secretary of this committee from the time of its organization till 1936. The committee pays this brief tribute to this long association and regrets the loss of his services.

I. REVISION OF TENTATIVE STANDARD

The committee recommends that the Tentative Specifications for Pearlitic Malleable Iron Castings (A 220 - 39 T)[1] be revised as appended hereto[2] and continued as tentative, as proposed by Subcommittee IV on Pearlitic and Alloy Malleable Iron.

This recommendation has been submitted to letter ballot of the committee which consists of 39 members; 29 members returned their ballots, of whom 26 have voted affirmatively, 1 negatively, and 2 members marked their ballots "not voting."

The negative vote was based on the belief that the elongations required in the proposed revised specifications could be obtained only by those manufacturers now making grade No. 35018 malleable iron. One of the affirmative voters expressed this view also.



NOTE.—Modifications may be made in the dimensions indicated above for those details of the specimen outside of the gage length as required by testing procedure and equipment.

FIG. 1.—Alternative Unmachined Tension Test Specimen.

II. TENTATIVE REVISIONS OF STANDARDS

An alternative unmachined tension test specimen as shown in the accompanying Fig. 1, proposed by Subcommittee I on Specimens and Methods of Testing, is recommended for publication as a tentative revision in the following standards:

---

[1] 1942 Book of A.S.T.M. Standards, Part I.

[2] These revised specifications were accepted as tentative by the Society and appear in the 1944 Book of A.S.T.M. Standards, Part I, p. 1408.

Standard Specifications for:[1]

Malleable Iron Castings (A 47 - 33; ASA G48.1-1942), and

Cupola Malleable Iron (A 197 - 39; G49.1-1942).

The large ends of the specimen may be changed to adapt it to individual testing machines. The proposed alternative specimen makes it possible to test malleable specimens and steel specimens without making any change in the testing machine holders. No difference in quality is anticipated.

This recommendation has been submitted to letter ballot of the committee which consists of 39 members; 32 members returned their ballots, of whom 30 have voted affirmatively, and 2 negatively.

The negative votes were based on a desire for further data as to the relative properties obtained in the new form of specimen as compared with that now in use.

The committee still has under consideration various other matters relating to proposed specifications for welding and a clarification of the phraseology in defining the yield point in the specifications for malleable iron castings.

A guest at the Cincinnati meeting reported difficulty in obtaining grade 35018 malleable iron in large castings.[3] Evidence was presented by consumers and producers that such material is normally available and is being regularly manufactured. Consequently no action was taken.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, C. O. Burgess.
Vice-Chairman, W. A. Kennedy.
Secretary, H. A. Schwartz.

This report has been submitted to letter ballot of the committee which consists of 39 members, 36 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

E. K. SMITH,
Chairman.

H. A. SCHWARTZ,
Secretary.

---

[3] The difficulties which had been experienced in obtaining material according to Specifications A 47, grade 35018, had been brought to the attention of the Society and were referred to the committee for investigation and consideration which resulted in an invitation being extended to the organization experiencing the difficulty to be represented at the meeting of the committee.—EDITOR'S NOTE.

EDITORIAL NOTE

Subsequent to the Annual Meeting Committee A-7 recommended to Committee E-10 on Standards that the Emergency Specifications for Malleable Iron Flanges, Pipe Fittings, and Valve Parts (ES - 20) be accepted for publication as tentative. This recommendation was accepted by the Standards Committee on August 28, 1944, and the tentative specifications appear in the 1944 Book of A.S.T.M. Standards, Part I, p. 1411, under the designation A 277 - 44 T.

REPORT OF COMMITTEE A-10

ON

IRON-CHROMIUM, IRON-CHROMIUM-NICKEL, AND RELATED ALLOYS

Committee A-10 on Iron-Chromium, Iron-Chromium-Nickel, and Related Alloys held two meetings during the year: in Cincinnati, Ohio, on March 1, 1944, and in New York, N. Y., on June 27, 1944, during the Annual Meeting of the Society, prior to the presentation of this report.

Few changes in committee personnel occurred during the year. The present membership is 80 of whom 36 are classified as producers, 32 as consumers, and 12 as general interest members.

The present officers of Committee A-10 have been re-elected for the ensuing term of two years. Elections in the subcommittees resulted in the re-election of the present subcommittee chairmen. Arba H. Thomas was appointed secretary of Subcommittee IV. As indicated later in this report, Subcommittee VI on Welding has been disbanded.

Subsequent to the 1943 Annual Meeting, Committee A-10 presented to the Society through Committee E-10 on Standards the following recommendations:

New Tentative Specifications for:

Corrosion-Resisting Chromium Steel Clad Plate, Sheet, and Strip (A 263 - 43 T),
Corrosion-Resisting Chromium-Nickel Steel Clad Plate, Sheet, and Strip (A 264 - 43 T), and
Nickel and Nickel-Base Alloy Clad Steel Plate (A 265 - 43 T).

These new tentative standards were accepted[1] by Committee E-10 on August 30, 1943, and assigned the A.S.T.M. serial designations indicated above. They appear in the 1943 Supplement to the Book of A.S.T.M. Standards, Part I.

At the same time Committee E-10 accepted revisions in the Emergency Alternate Provisions in the Standard Specifications for Corrosion-Resisting Chromium-Nickel Steel Plate, Sheet, and Strip (EA - A 167) and for Corrosion-Resisting Chromium and Chromium-Nickel Steel Plate, Sheet, and Strip for Fusion-Welded Unfired Pressure Vessels (EA - A 240), as recommended by Committee A-10. The revised emergency provisions were published in ASTM BULLETIN, No. 125, December, 1943, under the designations EA - A 167a and EA - A 240a, and have been issued in the form of stickers for attachment to the standards to which they apply.

I. REVISIONS OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends for immediate adoption revisions in the following three standards and accordingly asks for the necessary nine-tenths vote at the Annual Meeting in order that these modifications may be referred to letter ballot of the Society:

---

[1] In submitting these recommendations to Committee E-10 on Standards, Committee A-10 reported the following results of the letter ballot vote of a total of 48 ballots returned from a committee membership of 80: A 263 and A 264, affirmative 31, negative 0, ballots marked "not voting" 17; A, 265, affirmative 28, negative 0, ballots marked "not voting" 20.

Standard Specifications for Corrosion-Resisting Chromium and Chromium-Nickel Steel Plate, Sheet, and Strip for Fusion-Welded Unfired Pressure Vessels (**A 240 – 43**):[2]

The following changes in these specifications have been found desirable in order that the chemical composition requirements will be in accord with the interpretations of the A.S.M.E. Boiler Construction Code for use of stainless steel in the construction of fusion-welded unfired pressure vessels. This recommendation was prepared in cooperation with a special committee of the A.S.M.E. Boiler Code Committee. With the inclusion of these changes in Standard A 240 certain of the emergency alternate provisions in EA – A 240a will no longer be necesary and appropriate action to revise the latter will be taken through Committee E-10 on Standards.

TABLE I.—CHEMICAL REQUIREMENTS.

Grade	Type Number	Carbon,[a] max., per cent	Manganese, max., per cent	Phosphorus, max., per cent	Sulfur, max., per cent	Silicon, max., per cent	Chromium, per cent	Nickel, per cent
Grade A	410 modified	0.12	0.60	0.030	0.030	0.75	12.00 to 14.00	0.60 max.
Grade B	....	0.12	1.00	0.030	0.030	0.75	14.00 to 16.00	0.60 max.
Grade D	430 modified	0.12	1.00	0.030	0.030	0.75	16.00 to 18.00	0.60 max.
Grade S	304 modified	0.08	2.50	0.035	0.030	0.85	18.00 min.	8.00 min.
Grade M[b]	316 modified	0.08	2.50	0.035	0.030	0.85	17.00 min.	10.00 min.
Grade C[c]	347 modified	0.08	2.50	0.035	0.030	0.85	17.00 min.	9.50 min.
Grade T[d]	321 modified	0.08	2.50	0.035	0.030	0.85	17.00 min.	9.00 min.

[a] The carbon analysis shall be reported to the nearest hundredth of one per cent.
[b] Grade M shall have a minimum molybdenum content of 2.0 per cent.
[c] Grade C shall have a columbium content of not less than ten times the carbon content and not more than 1 per cent.
[d] Grade T shall have a titanium content of not less than five times the carbon content and not more than 0.60 per cent.

Table I.—Change the requirements as to chemical composition, where necessary, to read as shown in the accompanying Table I.

Table II.—Add the following test requirements for grade D:

Type number	430 modified
Tensile strength, min., psi	70 000
Yield strength, min., psi	35 000
Elongation in 2 in., min., per cent	22.0
Brinell hardness number, max	202
Rockwell hardness number, max	B88
Cold bend, deg	180

Section 12.—Reword the intergranular corrosion test as described in this section to state "that the corrosion test shall apply only to grades S, M, C, and T."

Section 17.—Change the requirement for No. 1 finish for plates from its present form: namely,

> *No. 1 Finish.*—Hot rolled, annealed, and either pickled or sand blasted, and pickled.

to read as follows:

> *No. 1 Finish:*
> (*a*) Hot rolled, annealed, and pickled, or
> (*b*) Hot rolled, annealed, grit or sand blasted, and passivated.

Standard Specifications for Corrosion-Resisting Chromium-Nickel Steel Plate, Sheet, and Strip (**A 167 – 43**):[2]

The following revision is recommended in these specifications due to the fact that the yield strength as determined by the alternate method may not necessarily be identical with an offset value of 0.2 per cent.

Section 7.—At the end of Paragraph (*a*) add the following sentence and note:

> The requirements of these specifications for yield strength will be considered as having been fulfilled, however, if the extension under load does not exceed 0.0063 in. in a 2-in. gage length.
>
> NOTE.—The value obtained in this manner should not, however, be taken as the actual yield strength for 0.2 per cent permanent set.

Add the following as a new Paragraph (*c*):

> (*c*) Between the yield strength and fracture of the specimen, the cross-head speed of the testing

---

[2] 1943 Supplement to Book of A.S.T.M. Standards, Part I.

machine shall be between ⅛ and ½ in. per in. of gage length per minute.

Section 15.—Change the description of No. 1 finish for plates to read the same as given above in the revision of Section 17 in Specifications A 240.

Standard Specifications for Corrosion-Resisting Chromium Steel Plate, Sheet, and Strip (A 176 – 43):[2]

Section 15.—Change the description of No. 1 finish for plates to read the same as given above in the revision of Section 17 in Specifications A 240.

Standard Specifications for High-Strength Corrosion-Resisting Chromium-Nickel Steel Sheet and Strip (**A 177 – 43**):[2]

For the same reason as stated above for the revision in Specifications A 167, the following revision in this standard is recommended:

Section 8.—At the end of Paragraph (*a*) add the following sentence and note:

> The requirements of these specifications for yield strength will be considered as having been fulfilled, however, if the extension under load for the specified yield strength does not exceed the specified values.
>
> Note.—The value obtained in this manner should not, however, be taken as the actual yield strength for 0.2 per cent permanent set.

Add a new Paragraph (*c*) reading the same as recommended above in Section 7 of Specifications A 167.

II. Revisions of Tentative Standards

As a result of cooperation with the A.S.M.E. Boiler Code Committee, revisions are recommended in the following two specifications for clad plate in order that they will also be in accord with the interpretations for the use of these materials in boiler and pressure vessel construction:

Tentative Specifications for Corrosion Resisting Chromium Steel Clad Plate, Sheet and Strip (**A 263 – 43 T**):[2]

Table I.—Omit all requirements for grade 6 (type 446).

Change the requirements as to chemical composition for grade 2 (type 410) to read the same as for grade A (type 410 modified) in the accompanying Table I.

In place of grade 4 (type 430) substitute grade B and grade D (type 430 modified) as shown in the accompanying Table I.

Tentative Specifications for Corrosion-Resisting Chromium-Nickel Steel Clad Plate, Sheet, and Strip (**A 264 – 43 T**):[2]

Table I.—Change the requirements as to chemical composition for types 304, 316, 347, and 321 to read as shown for the modified types 304, 316, 347, and 321 in the accompanying Table I.

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 80 members, with the results shown in Table II.

TABLE II.—ANALYSIS OF LETTER BALLOT VOTE.

Item	Affirmative	Negative	Ballots Marked "Not Voting"
I. Revision of Standards, Immediate Adoption			
Spec. for Corrosion-Resisting Chromium and Chromium-Nickel Steel Plate, Sheet, and Strip for Fusion-Welded Unfired Pressure Vessels (A 240 – 43)	44	0	11
Spec. for Corrosion-Resisting Chromium-Nickel Steel Plate, Sheet, and Strip (A 167 – 43)	44	0	11
Spec. for Corrosion-Resisting Chromium Steel Plate, Sheet, and Strip (A 176 – 43)	44	0	11
Spec. for High-Strength Corrosion-Resisting Chromium-Nickel Steel Sheet and Strip (A 177 – 43)	44	0	11
II. Revisions of Tentative Standards			
Spec. for Corrosion-Resisting Chromium Steel Clad Plate, Sheet, and Strip (A 263 – 43 T)	38	0	17
Spec. for Corrosion-Resisting Chromium-Nickel Steel Clad Plate, Sheet and Strip (A 264 – 43 T)	38	0	17
Spec. for Chromium-Nickel-Iron Alloy (25 - 12 Class) for High-Temperature Service	42	1	12

III. New Tentative Standard

The committee recommends for publication as tentative the new Specifications for Chromium-Nickel-Iron Alloy (25–12

Class) for High-Temperature Service,[3] prepared in cooperation with Committee B-4 on Electrical-Heating, Electrical-Resistance and Electric-Furnace Alloys.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Classification of Data (E. F. Cone, chairman; Russell Franks, secretary).—At present the subcommittee, with the cooperation of the Alloy Castings Institute which consists of representatives of the foundries manufacturing stainless steels in cast form, is obtaining data on the typical properties of cast chromium and chromium-nickel steels. The subcommittee has drawn up in table form an outline of the data on alloys in cast form needed for the publication of a set of companion tables to the "Tables of Data on Chemical Compositions, Physical and Mechanical Properties of Wrought Corrosion-Resisting and Heat-Resisting Chromium and Chromium-Nickel Steels,"[4] which, it is understood, will be issued jointly by the Alloy Castings Institute and A.S.T.M. The desired information is being solicited by the secretary of the A.C.I. from the various producers. Indications are that much of the information necessary for the preparation of the final publication will be available by the end of the year.

Subcommittee IV on Methods of Corrosion Testing (F. L. LaQue, chairman; Arba H. Thomas, secretary).—As the result of suggestions from various sources, the subcommittee has prepared certain changes in the Tentative Recommended Practice for Boiling Nitric Acid Test for Corrosion-Resisting Steels (A 262 – 43 T) which will be submitted to the Society through Committee E-10 on Standards subsequent to the Annual Meeting.

H. M. Brown and G. H. Baker, acting as a special subgroup, prepared a proposed tentative method for total immersion tests of corrosion-resisting steels based on the Tentative Method of Total Immersion Testing of Non-Ferrous Metals (B 185 – 43 T). This proposed method is being reviewed by the subcommittee; insufficient time has elapsed to permit final action.

Another special subgroup is engaged in formulating plans for a comprehensive program of atmospheric corrosion tests on corrosion-resisting steels, involving the exposure of various compositions in different mechanical forms to three types of atmospheres for periods up to 15 years. This program will be inaugurated as soon as it is practical to do so. In the meantime, it is proposed to expose a few pilot specimens as soon as possible as a future guide in the choice of test sites for the main program. This subgroup also is attempting to accumulate existing data on the behavior of corrosion-resisting steels in the atmosphere looking toward issuing a summary of this information prior to conducting the atmospheric corrosion tests being planned. Contributions to this summary will be welcomed by the subcommittee.

Subcommittee V on Mechanical Tests (T. F. Olt, chairman).—The subcommittee conducted a round-robin series of tests, participated in by five laboratories, to study the effects of rate of strain on the tensile properties of quarter-hard and half-hard tempers of stainless steel strip covered by the Standard Specifications for High-Strength Corrosion-Resisting Chromium-Nickel Steel Sheet and Strip (A 177 – 43). Each participating laboratory obtained results at four rates of strain. Four different types of extensometers were used. The results confirmed previous experiments in which low rates of strain gave high tensile strength and elongation compared to the rates normally used in tension testing. These data indicated that cross-head speeds between $\frac{1}{8}$ in. per inch of gage length per minute and $\frac{1}{2}$ in. per inch of gage length per minute, as suggested by the American Iron and Steel Institute, would greatly reduce the spread in tensile strength and elongation, and also permit testing at a reasonable rate.

---

[3] These specifications were accepted as tentative by the Society and appear in the 1944 Book of A.S.T.M. Standards, Part I, p. 1778.

[4] Issued December, 1942.

A second round-robin series of tests dealing with the effect of specimen preparation, especially edge preparation in sheet specimens, is now under way.

A communication was received from Joseph Winlock calling attention to the fact that yield strengths determined by the alternate method in the Standard Specifications for Corrosion-Resisting Chromium-Nickel Steel Plate, Sheet, and Strip (A 167 – 43) and for High-Strength Corrosion-Resisting Chromium-Nickel Steel Sheet and Strip (A 177 – 43) are not necessarily identical to 0.2 per cent offset yield strengths. In view of this, it was voted that Subcommittee V recommend to Subcommittee IX revisions in the sections on yield strength determinations in these two specifications. Further revisions are recommended in each of these specifications limiting the cross-head speed of the testing machine between $\frac{1}{8}$ and $\frac{1}{2}$ in. per inch of gage length per minute for speed of testing between the yield strength and fracture. These changes are given in detail earlier in this report.

Subcommittee VI on Metallography (Russell Franks, chairman).—Due to the pressure of other work, it has been impossible during the past year to make much progress in the work of the subcommittee which consists of attempting to find improved etching methods for detecting carbide in the grain boundaries of the austenitic chromium-nickel steels. However, as soon as the opportunity is available, additional work will be done on this problem.

Subcommittee VII on Welding (L. C. Bibber, chairman).—This subcommittee had been set up to develop recommended practices applicable to the welding of corrosion-resisting steels and methods for their examination. In view of the very extensive work in these directions undertaken by the American Welding Society, Subcommittee VII was authorized to carry on liaison work in this field. Since there was no longer a need for the subcommittee, Mr. Bibber asked to be relieved of its chairmanship as a result of which it was recommended that Subcommittee VII be discharged. Action was taken at the March meeting to effect this change.

Subcommittee VIII on Specifications for Wrought Products (J. K. Findley, chairman).—This subcommittee prepared a draft of specifications for hot-rolled and cold-drawn corrosion-resisting bars which was reviewed during the March meeting of the subcommittee. Some minor changes were suggested, as for example, increasing the carbon content to 0.15 per cent max. in types 302 and 303. At a recent meeting of the Technical Committee on Stainless Steels of the American Iron and Steel Institute, the size tolerances of bars covered by these specifications were discussed; the results of this discussion have been considered in preparing the final draft which is now being balloted upon. It is expected that these specifications will be submitted to the Society through Committee E-10 on Standards subsequent to the Annual Meeting.

The subcommittee is also preparing specifications for spring wire, completion of which is being actively prosecuted.

Subcommittee IX on Specifications for Flat Products (C. C. Snyder, chairman).—In view of discussion at a joint meeting of the members of the Boiler Code Committee of The American Society of Mechanical Engineers and Subcommittee IX of Committee A-10, this subcommittee prepared revisions in the Standard

Specifications for Corrosion-Resisting Chromium and Chromium-Nickel Steel Plate, Sheet, and Strip for Fusion-Welded Unfired Pressure Vessels (A 240 – 43) which are being recommended for immediate adoption.

It is also recommended that Emergency Alternate Provision EA – A 240a be revised by the omission of the requirement lowering the titanium content for grade T since no shortage or prospect of future shortage of ferro-titanium exists.

The subcommittee has under consideration revisions in the Tentative Specifications for Corrosion-Resisting Chromium Steel Clad Plate, Sheet, and Strip (A 263 – 43 T) and for Chromium-Nickel Steel Clad Plate, Sheet, and Strip (A 264 – 43 T) to bring them in line with revised Specifications A 240. The Boiler Code Committee suggested that type 446 composition be omitted from Specifications A 263 because unsatisfactory welding has been experienced with this grade. A new composition containing 14 to 16 per cent chromium, corresponding to that added to Specifications A 240, was recommended for incorporation in Specifications A 263. It is hoped that the proposed revisions in these three specifications can be submitted to the Society in the near future.

Based on information supplied by Subcommittee V, Subcommittee IX recommends for immediate adoption revisions in the Standard Specifications for Corrosion-Resisting Chromium-Nickel Steel Plate, Sheet, and Strip (A 167 – 43) and for High-Strength Corrosion-Resisting Chromium-Nickel Steel Sheet and Strip (A 177 – 43) as given earlier in this report.

Subcommittee X on Specifications for Castings (J. J. Kanter, chairman).—The subcommittee has been working on specifications for a 25 per cent chromium, 12 per cent nickel alloy to include high-temperature test requirements. Agreement has been reached between this subcommittee, A.S.T.M. Committee B-4 on Electrical-Heating, Electrical-Resistance, and Electric-Furnace Alloys, and the American Petroleum Institute with respect to these specifications and it is also planned to consult with the Alloy Castings Institute. It is hoped that these specifications can be submitted to Committee A-10 shortly.

Subcommittee XI on Specifications for Tubular Products (J. J. B. Rutherford, chairman).—The joint committee consisting of members from Subcommittee IX on Steel Tubing and Pipe of Committee A-1, and Subcommittee XI of Committee A-10, organized to prepare specifications for stainless steel tubing for various applications, including austenitic and ferritic seamless and welded tubes for general service, materials for cracking stills, and tubes for the dairy and food industries, has submitted four specifications for stainless steel tubing. It is expected that final agreement on these specifications may be reached at the June meeting. The standard compositions are to be included in these specifications and emergency alternate provisions, only to be effective for the duration are to be submitted for publication in the form of a sticker for attachment to the specifications. It was necessary to harmonize these compositions with those included in the Standard Specifications for Seamless Alloy-Steel Boiler and Superheater Tubes (A 213 – 42) and in the Tentative Specifications for Seamless Alloy-Steel Pipe for Service at Temperatures from 750 to 1100 F. (A 158 – 42 T) which are under the jurisdiction of Committee A-1.

The present officers of the committee have been re-elected for the ensuing term of two years.

This report has been submitted to letter ballot of the committee which consists of 80 members; 55 members returned their ballots, of whom 44 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the committee,

JEROME STRAUSS,
Chairman.

H. D. NEWELL,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee A-10 presented as joint sponsor with Committee A-1 on Steel, the following recommendations to the Society through Committee E-10 on Standards:

New Tentative Specifications for:

Seamless and Welded Ferritic Stainless Steel Tubing for General Service (A 268 - 44 T) and Emergency Alternate Provisions EA - A 268,
Seamless and Welded Austenitic Stainless Steel Tubing for General Service (A 269 - 44 T) and Emergency Alternate Provisions EA - A 269,
Seamless and Welded Austenitic Stainless Steel Tubing for Dairy and Food Industry (A 270 - 44 T) and Emergency Alternate Provisions EA - A 270, and
Seamless Austentic Chromium-Nickel Steel Still Tubes for Refinery Service (A 271 - 44 T) and Emergency Alternate Provisions EA - A 271.

These recommendations were accepted by Committee E-10 on October 25, 1944, and the new tentative specifications and emergency alternate provisions appear in the 1944 Book of A.S.T.M. Standards, Part I.

On December 27, 1944, the Standards Committee accepted the following recommendations of Committee A-10:

Tentative Specifications for:

Hot-Rolled and Cold-Finished Corrosion Resisting Bars (A 276 - 44 T),

Tentative Method of:

Total Immersion Testing of Stainless Steels (A 279 - 44 T),

Revision of Tentative Recommended Practice for:

Boiling Nitric Acid Test for Corrosion-Resisting Steels (A 262 - 43 T), and

Withdrawal of Emergency Alternate Provisions in the

Standard Specifications for Corrosion-Resisting, Chromium and Chromium-Nickel Steel Plate, Sheet and Strip, for Fusion-Welded Unfired Pressure Vessels (EA - A 240a).

The new and revised tentatives also appear in the 1944 Book of A.S.T.M. Standards, Part I.

COOPERATIVE STUDY OF EFFECT OF RATE OF STRAIN ON THE TENSILE PROPERTIES OF STAINLESS SHEETS

Report of Subcommittee V on Mechanical Tests

It has been quite generally recognized for some time that tension tests of the austenitic stainless steels are quite sensitive to variations in testing. This is particularly true of the rate of strain when testing the high-strength 17 per cent chromium, 7 per cent nickel stainless steels. As these high-strength materials are produced by cold rolling and since austenitic stainless steel transforms when cold worked, the amount of transformation being dependent upon the amount of work and likely upon rate of working, it is to be expected that rate of strain would affect the tensile properties.

The various specifications governing the production of stainless steel sheet and strip differ widely in the allowable rates of strain specified for conducting tension tests. Accordingly, it was the aim of Subcommittee V to investigate the effect of rate of strain, within practical limits, and to recommend as a standard a limiting range which would decrease the wide spread in results and yet permit testing at a rate compatible with normal laboratory procedures.

A preliminary program was inaugurated to compare the results obtained by the following five cooperative laboratories using their usual practice for tension testing of stainless steel sheet:

American Rolling Mill Co.
Carnegie-Illinois Steel Corp.
Dow Chemical Co.
International Nickel Co.
Union Carbon and Carbide Co.

All tests both in the original program and the one which later developed were conducted on specimens of standard dimensions, 0.5 in. in width with a gage length of 2 in. taken with the long axis perpendicular to the direction of rolling.

Sets of tension specimens were prepared from triplicate samples of material conforming to the following A.S.T.M. specifications and submitted to the cooperating laboratories for tests:

Standard Specifications for Corrosion-Resisting Chromium Steel Plate, Sheet, and Strip (A 176 - 43), grade 4 (type 430), in the annealed state.

Standard Specifications for Corrosion Resisting Chromium-Nickel Steel Plate, Sheet, and Strip A 167 - 43), grades 1, 3, 5, and 6 (types 301, 304, 321 and 347), all in the annealed state.

Standard Specifications for High-Strength Corrosion-Resisting Chromium-Nickel Steel Sheet and Strip (A 177 - 43), in the half-hard and three-quarter hard tempers.

Yield strength determinations were obtained by the 0.2 per cent offset method (manually plotted curves) by three of the laboratories and by the 0.5 per cent extension under load method (autographically recorded curves) by the other two laboratories. Cross-head speeds of 0.02 to 0.11 in. per min. were used to the yield strength and 0.28 to 0.51 in. per min. from yield strength to fracture with the exception of one laboratory which used extremely slow speeds of 0.08 to 0.148 in. per min.

TABLE I.—EFFECT OF RATE OF STRAIN ON TENSILE PROPERTIES OF HIGH TENSILE STRENGTH STAINLESS STEEL CONFORMING TO A.S.T.M. SPECIFICATIONS A 177.[a]

Laboratory	Rate of Strain (Cross-head Speed) in. per min.		Yield Strength (0.2 per cent offset), psi.	Tensile Strength, psi.	Elongation in 2 in., per cent
	To Yield Strength	Yield Strength to Fracture			
HALF-HARD TEMPER					
1	0.02	0.02	115 800	164 200	30.3
2	0.02	0.02	125 200	166 000	29.3
3	0.02	0.02	120 600	161 300	25.5
4	0.02	0.02	121 100	163 300	23.5
5	0.017	0.017	116 700	161 400	29.7
Avg	..	..	119 900	163 200	27.7
1	0.05	0.05	115 600	162 500	26.7
2	0.05	0.05	114 800	161 300	25.3
3	0.05	0.05	116 100	159 000	25.7
4	0.05	0.05	119 700	161 700	21.5
5	0.05	0.05	120 500	161 500	27.7
Avg.	..	..	117 300	161 200	25.4
1	0.05	0.2	114 900	160 100	22.3
2	0.05	0.2	118 400	159 800	19.8
3	0.05	0.2	115 700	155 400	19.8
4	0.05	0.2	119 500	161 900	18.5
5	0.05	0.2	122 900	160 000	21.0
Avg.	..	..	118 300	159 400	20.3
1	0.05	0.5	116 400	158 300	19.3
2	0.05	0.5	118 700	159 300	18.0
3	0.05	0.5	115 500	154 000	17.7
4	0.05	0.5	120 500	160 300	18.0
5	0.05	0.5	123 600	158 300	18.3
Avg.	..	..	118 900	158 000	18.3
QUARTER-HARD TEMPER					
1	0.02	0.02	99 000	146 000	40.0
2	0.02	0.02	103 200	147 300	37.0
3	0.02	0.02	102 500	145 700	38.2
4	0.02	0.02	102 600	145 900	29.0
5	0.017	0.017	104 100	146 800	34.7
Avg.	..	..	102 300	146 300	35.8
1	0.05	0.05	99 300	144 300	34.7
2	0.05	0.05	103 800	148 000	35.2
3	0.05	0.05	103 200	144 800	33.0
4	0.05	0.05	102 700	145 700	28.0
5	0.05	0.05	108 100	146 300	38.2
Avg.	..	..	103 400	145 800	33.8
1	0.05	0.2	99 400	140 900	29.8
2	0.05	0.2	104 000	141 500	28.7
3	0.05	0.2	102 000	139 200	29.7
4	0.05	0.2	102 600	143 600	24.0
5	0.05	0.2	108 400	140 800	27.5
Avg.	..	..	103 300	141 200	27.9
1	0.05	0.5	99 700	138 700	25.5
2	0.05	0.5	102 400	138 500	24.0
3	0.05	0.5	101 800	135 300	24.2
4	0.05	0.5	103 500	141 900	23.0
5	0.05	0.5	107 100	138 000	24.2
Avg.	..	..	102 900	138 500	24.2

[a] All values are an average of three tests.

There were no appreciable definite effects due to speed of testing noted on the five grades of stainless steel tested, with the exception of those tests made at the very slow rates of strain which exhibited higher tensile strength and elongation values. The yield strengths obtained by the 0.5 per cent extension under load method were generally slightly higher than those obtained by the 0.2 per cent offset method. There was, however, considerable variation in the results obtained by the three laboratories using the 0.2 per cent offset method.

From the results of the first program it was deemed advisable to continue the work having all participating laboratories use the same rates of strain and determine yield strengths at 0.2 per cent offset. Sets of triplicate samples of material conforming to Specifications A 177 in the quarter-hard and half-hard tempers were submitted for testing to the laboratories of the five previously mentioned cooperating companies. Speeds of testing used were as follows:

- 0.02 in. per min. throughout (one laboratory used 0.0168 in per min.).
- 0.05 in. per min. throughout.
- 0.05 in. per min. to yield strength, and 0.2 in. per min. from yield strength to fracture.
- 0 05 in. per min. to yield strength, and 0.5 in. per min. from yield strength to fracture.

Four laboratories used manually plotted curves for yield strength determinations and one used autographically recorded curves. The test results are shown in Table I.

The results obtained confirm those of the previous test in which low rates of strain produced higher tensile strength and elongation values as compared to rates normally used. The softer the temper the more pronounced is the effect of rate of strain. In the range of speeds tested the yield strength is not materially affected by increasing rate of strain while the ultimate strength decreases slightly and the elongation decreases markedly. These results show some agreement with work done on stainless steel in connection with rate of strain as reported in the paper by P. G. Jones and H. F. Moore on "An Investigation of the Effect of Rate of Strain on the Results of Tension Tests of Metals."[1]

On the basis of the results obtained in this study, the subcommittee recommended the adoption of the proposal of the American Iron and Steel Institute to limit the cross-head speed to $\frac{1}{8}$ to $\frac{1}{2}$ in. per in. of gage length per minute for speed of testing between the yield strength and fracture. No recommendation was made on rate of strain or rate of loading up to the yield strength pending further investigation of that phase of the problem. It is planned also to continue the cooperative program to determine the effects of method of specimen preparation on the mechanical properties of stainless steels.

Respectfully submitted on behalf of the subcommittee,

T. F. OLT,
Chairman.

---

[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 40, p. 610 (1940).

REPORT OF THE RESEARCH COMMITTEE
ON
FATIGUE OF METALS

During the past year the members of the Research Committee on Fatigue of Metals together with many other experimenters in this field have been engaged for the most part in work directly or indirectly connected with the war effort. Most of the results of this work have not been available for publication and cannot be summarized at this time. The members have been extremely busy, and it has not been feasible to hold a formal meeting during the year. As indicated in such formal and informal reports as have been available, the following features have been of rather special interest during the year:

1. Fatigue strength of metals and metal parts under definite limited life as well as the endurance limit under an indefinitely long period of service.
2. The effect of surface conditions. Data are available which indicate that extremely high polish does not increase to any marked degree the fatigue strength of many metals above the fatigue strength when tested with an ordinary shop polish.
3. Surface treatments for increasing fatigue strength including surface heat treating, carburizing, nitriding, and shot blasting.
4. Size effect on fatigue strength.
5. Fatigue strength of welded joints.
6. The effect of aging of metals, especially of light alloys, on fatigue strength.
7. The growing development of heavy apparatus for full-sized tests of machine parts and specimens.
8. Fatigue strength of plastics. Although this subject does not come strictly under the fatigue strength of metals, it has received much attention.

The research on the effect of size of specimen on fatigue strength carried on at the University of Illinois has been greatly retarded by the loss of men to the armed services and to war industries. It has also been very difficult to obtain apparatus and equipment. However, there is presented as an Appendix to this report, a Third Progress Report on the Effect of Size of Specimen on Fatigue Strength of Three Types of Steel.

This report has been submitted to letter ballot to the committee which consists of 24 members; 17 members returned their ballots, of whom 15 have voted affirmatively and 2 negatively.

Respectfully submitted on behalf of the committee,

H. F. MOORE,
Chairman,

APPENDIX

THIRD PROGRESS REPORT ON THE EFFECT OF SIZE OF SPECIMEN ON FATIGUE STRENGTH OF THREE TYPES OF STEEL

PREPARED BY D. MORKOVIN[1] AND H. F. MOORE[1]

SYNOPSIS

Fatigue tests of specimens of S.A.E. 1035 steel were made on various sizes of specimens. These specimens had been thoroughly annealed to remove any residual stresses. The annealing was done *after* the machining and polishing of the specimens, and was done in a vacuum furnace so that the polished surfaces remained bright after annealing. A positive size effect was found for these annealed specimens, indicating that size effect may be present even if there are no appreciable residual stresses.

A study of the test data obtained so far has been made by means of the Neuber analysis. It was found that values of the constants in the Neuber analysis could be chosen so that the endurance limits predicted by the Neuber analysis and those found by actual fatigue tests were in fairly good agreement. Size effect in unnotched specimens as found by fatigue tests checked reasonably well with the results of the Neuber analysis, based on the assumption that the inherent defects in steel may be regarded as equivalent to small notches in their weakening effect.

A method of obtaining one of the Neuber constants by means of two series of fatigue tests, one on unnotched specimens and the other on notched, is described and checked against the experimental results obtained.

The possibility of reduced fatigue strength of still larger specimens owing to the probability of the occurrence of localized macro-defects in such specimens at critical regions near the surface is considered, and the desirability of the initiation of a program of fatigue tests on various types of non-ferrous metal is emphasized.

Scope of Investigation:

The investigation of "size effect" on fatigue strength was planned to cover three main lines of study: (1) effect of size on unnotched, polished specimens, (2) effect of size on notched, polished specimens, and (3) the question whether any internal or residual stresses present in the machined and polished specimens might be at least partially responsible for the different endurance limits of specimens of the same metal and shape but of different size.

The first and second progress reports considered the first and second of these objectives (**1**, **2**).[2]

---

[1] Formerly Research Associate in Theoretical and Applied Mechanics, and Research Professor of Engineering Materials, Emeritus, respectively, University of Illinois, Urbana, Ill.

[2] The boldface numbers in parentheses refer to the reports and papers appearing in the list of references appended to this paper, see p. 154.

This third progress report treats of the third objective and includes a discussion of size effect based on Neuber's theory.

Metals Tested and Testing Machines:

The steels tested were from the same bars as those reported on in 1942: namely, (1) 15 bars each $3\frac{1}{2}$ in. in diameter and 20 ft. long of an S.A.E. 1020 carbon steel hot-rolled and furnished by the Carnegie-Illinois Steel Corp., (2) 16 bars each $3\frac{1}{2}$ in. in diameter and 19 ft. long of an S.A.E. 1035 steel hot-rolled and furnished by the Carnegie-Illinois Steel Corp., and (3) 11 bars each 3 in. in diameter and in lengths varying from 17 to 21 ft. of S.A.E. X4130 steel heat treated to approximately 300 Brinell hardness and furnished by the Timken Roller Bearing Co. Table I gives the chemical composition and Table II the mechanical properties of the steels tested.

Figure 1 shows the microstructure of the steels tested in the condition in which

TABLE I.—HEAT ANALYSES OF THE STEELS USED IN SIZE EFFECT TESTS.

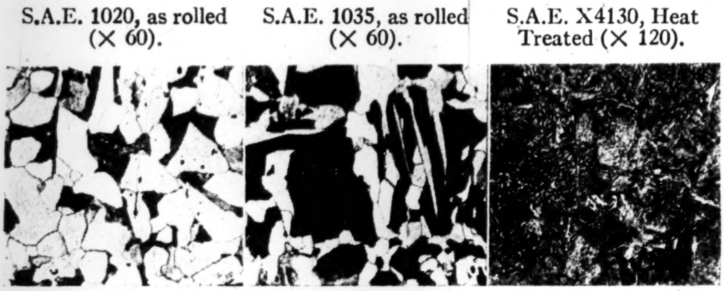
Steel	Chemical Content, per cent						
	Carbon	Manganese	Silicon	Chromium	Molybdenum	Sulfur	Phosphorus
S.A.E. 1020	0.22	0.46	0.20	....	....	0.033	0.014
S.A.E. 1035	0.34	0.78	0.24	....	....	0.028	0.016
S.A.E. X4130	0.31	0.55	....	1.08	0.20	0.019	0.017

TABLE II.—MECHANICAL PROPERTIES OF THE STEELS USED IN SIZE EFFECT TESTS.

Steel	Yield Strength, psi.	Tensile Strength, psi.	Elongation in 2 in., per cent	Reduction of Area, per cent
S.A.E. 1020, as rolled	32 300[a]	62 000	28.0	5
S.A.E. 1035, as rolled	47 200[a]	87 600	25.0	5
S.A.E. 1035, annealed	43 400[a]	77 600	27.5	54
S.A.E. X4130, heat-treated	115 600[b]	141 800	17.6	6

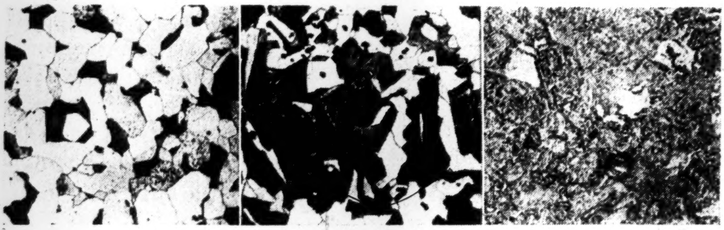
[a] Yield point by halt of pointer of load-indicator dial.

[b] Yield strength by 0.2 per cent offset from stress-strain diagram.



S.A.E. 1020, as rolled (× 60). S.A.E. 1035, as rolled (× 60). S.A.E. X4130, Heat Treated (× 120).

Longitudinal Sections.



Transverse Sections.

FIG. 1.—Photomicrographs of Steel.
Photomicrographs by Prof. W. C. Bruckner, University of Illinois.

all the specimens reported in the first two progress reports (of which, the results are recapitulated in Fig. 7) were tested. Figure 2 shows the microstructure of those few specimens which were annealed at 1500 F. for 2 hr. in vacuum.

The testing machines were the same machines used in making the tests of the unnotched bars which were reported on in 1942 (1). The type of machine is shown in Fig. 3.

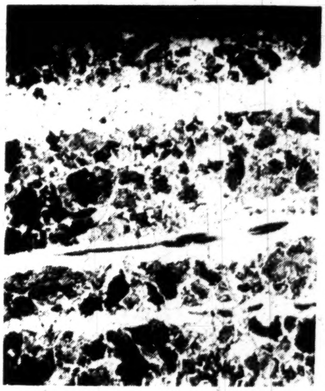


FIG. 2.—Photomicrograph of S.A.E. 1035 Steel, Vacuum Annealed (× 60).

Longitudinal section. The edge shown at the top of the micrograph is at the polished edge of the specimen.

Photomicrograph by Prof. W. C. Bruckner, University of Illinois.

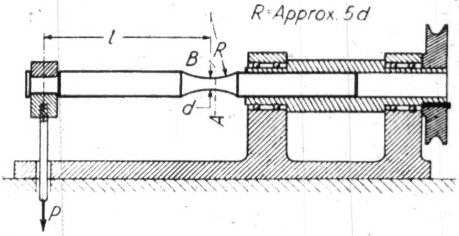


FIG. 3.—Diagram of Typical Test Specimen (Unnotched) and Rotating-Cantilever Testing Machine.

Fatigue Specimens:

In cutting fatigue specimens from the rods as furnished, the axis of the largest specimen was the same as the axis of the bar. In cutting the other specimens from the bars, it was attempted to bring the inner end of the minimum diameter as nearly as possible to the same radius from the axis of the bar as was the surface of the largest specimen. The location of the specimens in the bars is shown in Fig. 4.

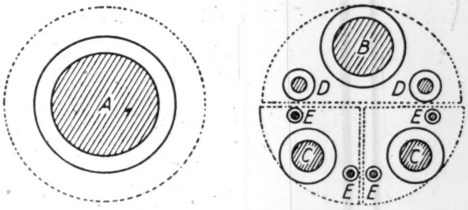


FIG. 4.—Location of Specimens in the Rolled Bars.

A = 1½-, 1¾-, and 1⅞-in. specimens.
B = 1-in. specimens.
C = ½-in. specimens.
D = ¼-in. specimens.
E = ⅛-in. specimens.

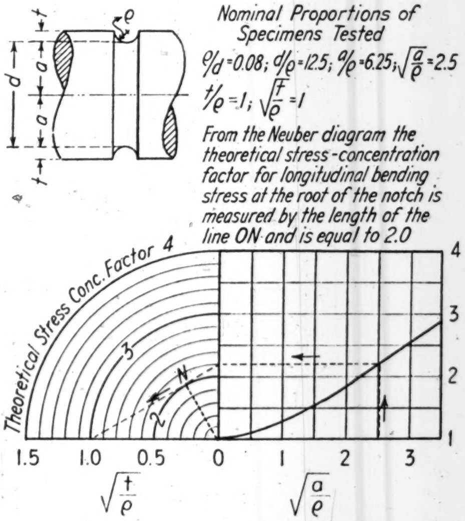


FIG. 5.—Nominal Proportions of Notched Specimens and Neuber's Diagram Used for the Determination of the Theoretical Stress Concentration Factor k_t in Pure Bending of Round Members with Circumferential Notch.

When it is desired to use this Neuber diagram for values of $\sqrt{a/\rho}$ greater than 3.5, taking advantage of the fact that the upper part of the curve is very nearly a straight line, values of ordinate y corresponding to values of $\sqrt{a/\rho}$ greater than 3.5 may be computed from the equation $y = 0.400 + 0.715 \sqrt{a/\rho}$. The value of y is read off the vertical scale at the right hand edge of the diagram.

The nominal proportions of the

notched section of the specimen are shown in Fig. 5. The notch in each notched specimen was a semi-circular groove with a radius equal to 0.08 times the minimum diameter of the specimen at the root of the notch.

Figure 5 shows also the Neuber diagram(3)[2] for theoretical bending stress concentration at the root of a groove of hyperbolic profile with radius of curvature ρ, depth of notch t, and minimum diameter of the specimen at the root of notch $2a$. It was assumed that the stress concentration factor at the root of a semi-circular groove does not differ appreciably from the stress concentration factor at the root of a hyperbolic groove of the same radius of curvature and

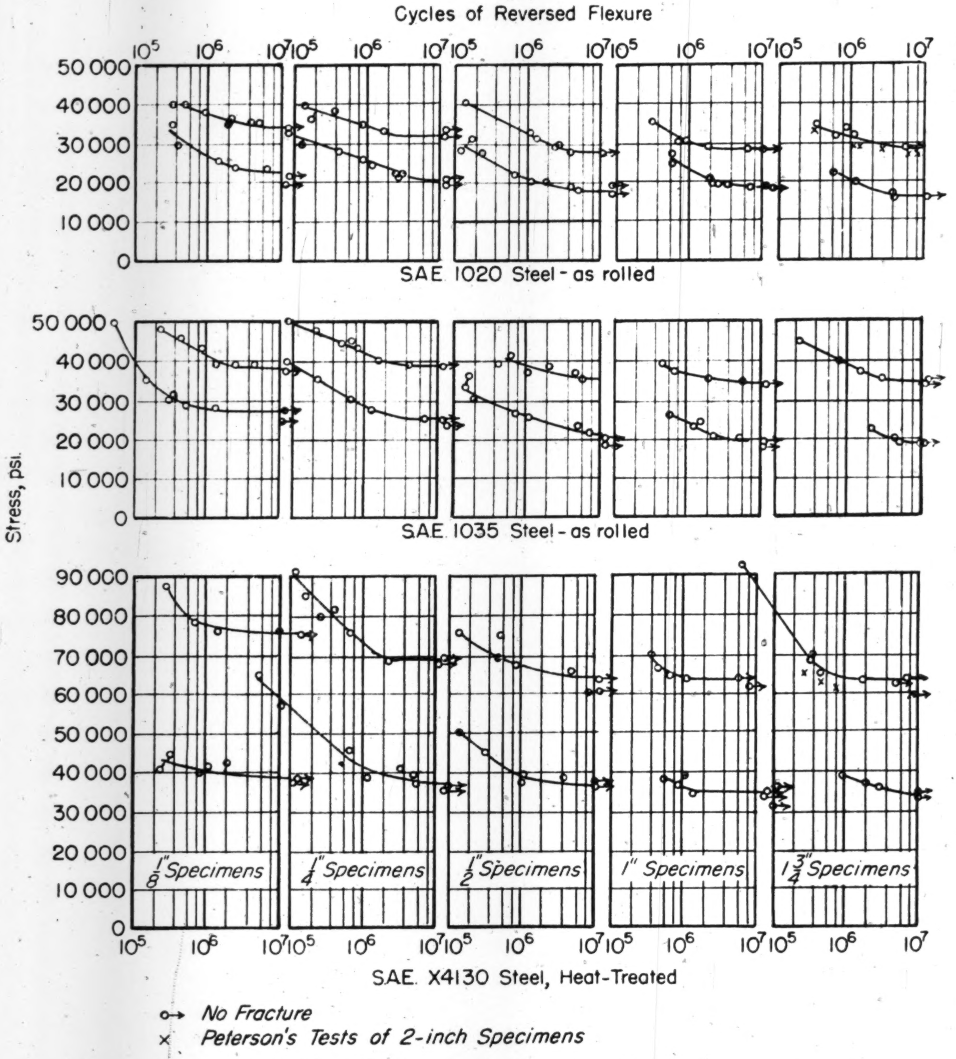


FIG. 6.—*S-N* Diagrams for Specimens Tested.
S-N diagrams for S.A.E. 1035 steel annealed shown in Fig. 9.

depth t. Using the diagram in Fig. 5 as indicated by the arrows, the value of the theoretical stress-concentration factor k_t at the root of the groove of the proportions common to all notched specimens tested was found to be 2.0. This theoretical stress concentration factor k_t is the ratio $\frac{s_1}{s_n}$, in which s_1 denotes the maximum longitudinal stress at the root of the notch (as calculated by Neuber), and s_n denotes the nominal longitudinal stress in the same fiber, as computed by the ordinary flexure formula.

Polishing of Specimens:

The unnotched specimens of nominal 2, 1, ½, and ¼-in. sizes and notched ones of nominal 2-in. size were polished with Metalite cloth grit 120 and finished with Aloxite cloth grit 240, with oil. The unnotched specimens of ⅛-in. size were finished with Emery paper grit No. 00, with oil. The cloth or paper was held on a mandrel and both specimen and mandrel rotated. Notches in specimens of sizes 1, ½, ¼, and ⅛-in. were polished with a rotating soft copper wire of proper diameter, flooded with oil with fused alumina size 240 (alundum grain), and finished in the same manner with silicon carbide grain No. FFF. The axis of the swiftly rotating mandrel was held at approximately 90 deg. with the axis of the slowly rotating specimen.

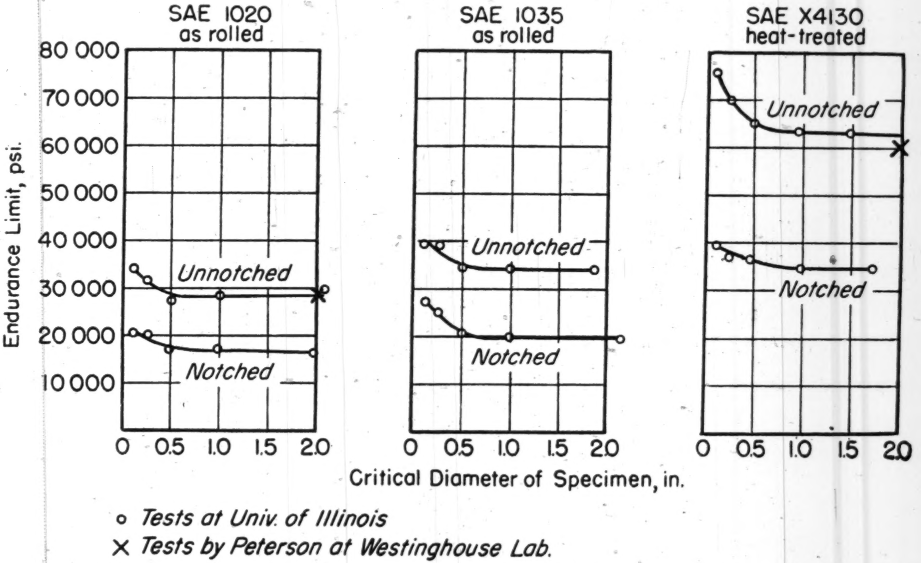


FIG. 7.—Effect of Size of Specimen on Endurance Limit of Unnotched and of Notched Rotating-Cantilever Specimens.

Data and Results of Tests:

The data of the fatigue tests on the S.A.E. 1020 as rolled, the S.A.E. 1035 steel as rolled, and the S.A.E. X4130 steel, heat treated, are given in Fig. 6 as S-N diagrams for the fatigue tests. The test data and results of the fatigue tests of specimens of S.A.E. 1035 steel, annealed, are discussed in a later section.

Figure 7 shows graphically the falling off of the endurance limit as the size of specimen is increased from ⅛ in. in diameter up to some value between ½ in. and ¾ in. in diameter. The fatigue

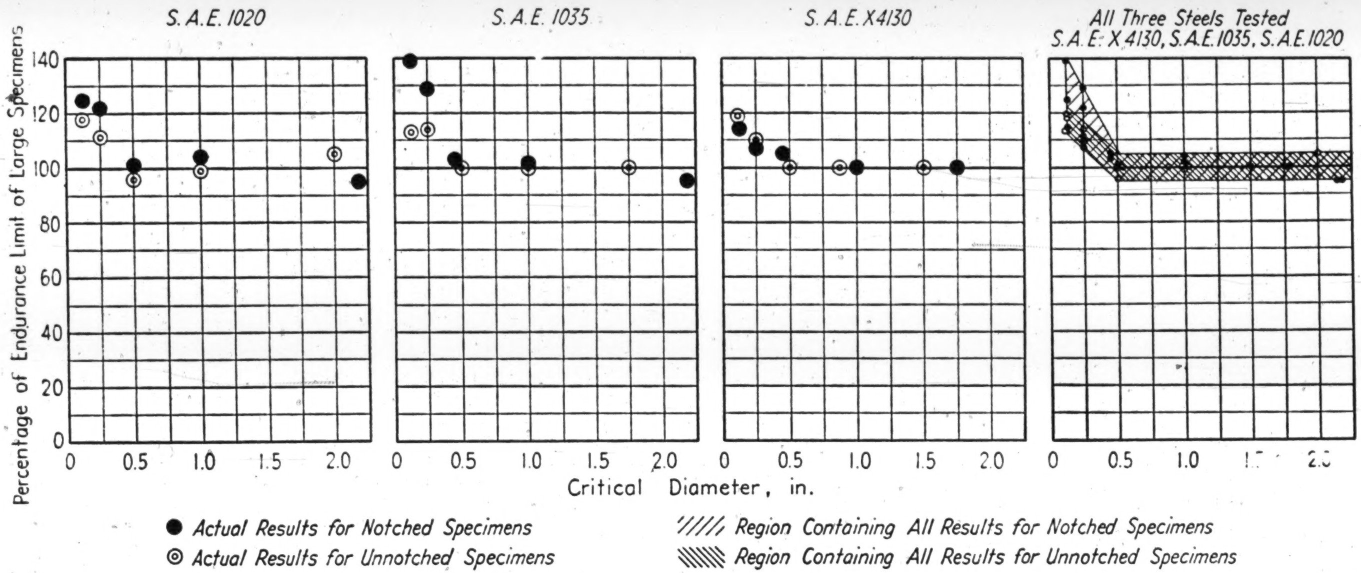


FIG. 8.—Endurance Limits in Reversed Bending of Unnotched and Notched Rotating-Cantilever Specimens of Various Sizes, Expressed as Percentages of the Average Endurance Limits of Large Specimens (Diameter 1 in. or greater).

strength of parts larger than 2 in. in diameter is discussed in a later section.

Figure 8 shows the effect of size on fatigue strength in terms of percentages of the endurance limit of specimens with diameters of 1 in. and over. It is to be noted that on the percentage basis all the test results fit into a narrow strip on the right-hand diagram of Fig. 8.

Size Effect in a Steel Free from Internal Stress:

It has often been suggested that a major, perhaps the major, cause of the reduced strength of large fatigue specimens, or of machine parts subjected to repeated stress, may be the larger residual stresses to be found in large parts, especially heat-treated machine parts. It was planned to make a rather elaborate study of the residual stresses in the different sizes of specimens tested, but the reduction of the laboratory force, due to war conditions, made this impossible. However some tests were made of different sizes of specimens of S.A.E. 1035 steel which had been thoroughly annealed and all residual stresses presumably removed. Specimens of three different sizes ($\frac{1}{8}$, $\frac{1}{4}$, and $\frac{1}{2}$ in. in diameter, the sizes for which the size effect had been most pronounced in the "as rolled" specimens) were machined, polished, and then annealed in vacuum[3] and thus all residual stresses due to previous rolling, machining and polishing, presumably were removed. All the specimens were packed together in steel wool and inserted in a sealed alloy steel tube. The tube was evacuated to 75 μ before heating was started. The rate of heating was controlled so that 100 to 125 μ were never exceeded. The rate of heating and cooling never exceeded 200 F. per hr. After bringing up the temperature to 1500 F., the specimens were held at this temperature for 2 hr. and then slowly cooled, still under vacuum. The polished surface of the specimens remained bright after annealing.

If during the annealing process there occurred any surface decarburizing or grain boundary corrosion in the surface layers of the metal there might be set up a "negative" size effect which would tend to mask any "positive" size effect remaining in the specimen after annealing. The decarburization of the surface layer would extend to approximately the same depth in the different sizes of specimens. The same would be true for any grain boundary corrosion in surface layers. Either of these would weaken the metal, and the percentage of thickness of the metal affected would be greatest in the specimens of smallest diameter. As a matter of fact the photomicrographs shown in Fig. 2 show no evidences of surface decarburization. If therefore a positive size effect is still apparent even after the recrystallization, and in spite of any opposite tendency due to any decarburization or grain boundary corrosion, evidence is given that size effect in fatigue may still be present even if there are no appreciable residual stresses in a specimen. Such a positive size effect is shown in Fig. 9 which gives the *S-N* diagrams for the annealed specimens of S.A.E. 1035 steel. The larger specimens show distinctly less fatigue strength than do the smaller specimens, except that for the notched specimens the $\frac{1}{2}$-in. specimens and the 2-in. specimens developed about the same fatigue strength.

These tests, although few in number, furnish a clear case of a positive size effect in a steel from which residual stresses had been removed by thorough annealing.

---

[3] The annealing was done in the Metallurgical Laboratory of the Department of Mining and Metallurgical Engineering of the University of Illinois by W. H. Bruckner, Research Assistant Professor of Metallurgical Engineering, by whom also the photomicrographs shown in Figs. 1 and 2 were made.

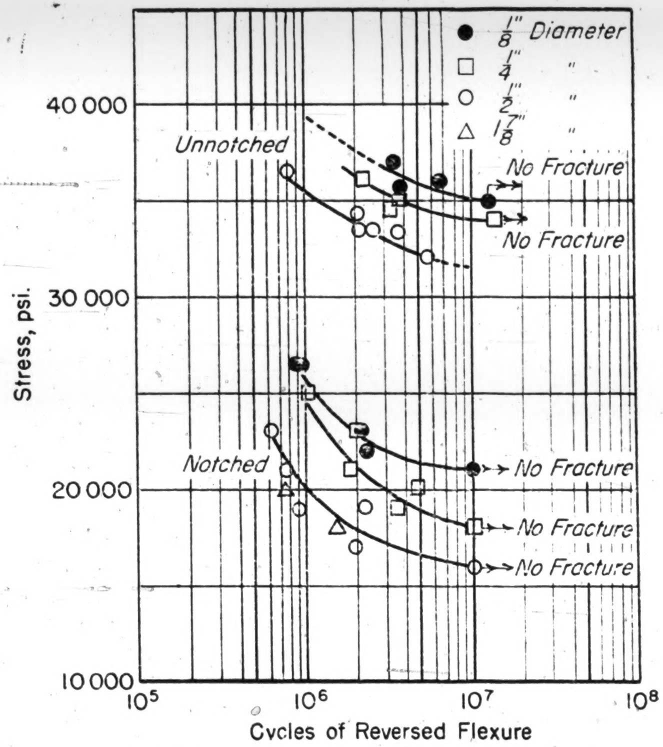


FIG. 9.—*S-N* Diagrams for ⅛, ¼, ½, and 1⅞-in. Specimens of S.A.E. 1035 Steel Vacuum Annealed at 1500 F., after Machining and Polishing.

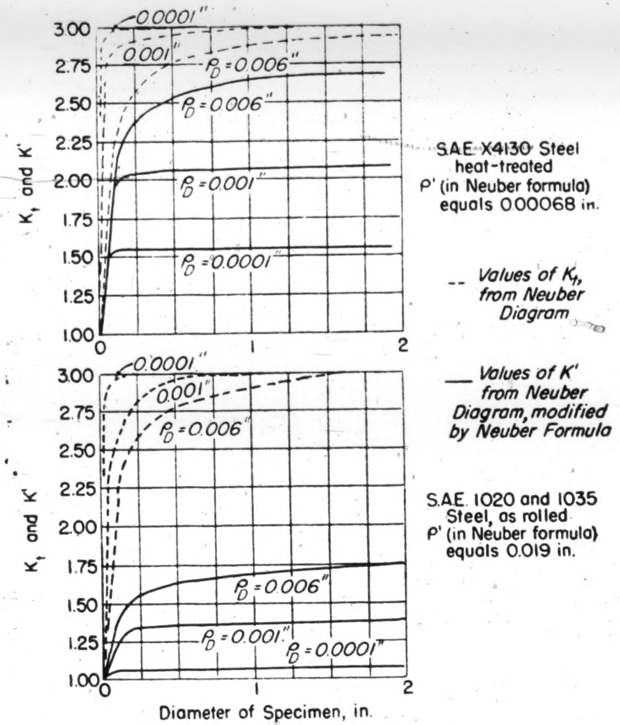


FIG. 10.—Computed Values of k_t, the Stress Concentration Factor and k', the Strength-Reduction Factor for Unnotched Specimens with "Defects" Equivalent in Reducing Fatigue Strength to a Semicircular Notch with Radius ρ_D.

INHERENT DEFECTS AS A POSSIBLE EXPLANATION OF "SIZE EFFECT"

Any minute inherent defects in the material of a machine part are presumably distributed at random throughout the material, and any such defect acts to set up stress concentrations in its immediate vicinity. Such defects which are on the surface of the part, or which emerge or are caused during a machining process are most dangerous, because the surface "fibers" at any section are usually subjected to maximum stress. Neuber's analysis (3) is here suggested as a method of estimating the effect of such "stress raisers." This involves the assumption that the stress concentration set up may be regarded as equivalent to that set up by a semicircular notch of radius ρ_D. The choice of a value for ρ_D is a rather speculative matter, but in this paper a value is found by trial and error which fits the results of fatigue tests of unnotched specimens[4] and then some consideration is given to the possible physical significance of the values found.

If a value of ρ_D is estimated or assumed, then Neuber's diagram (Fig. 5) may be used to determine the "theoretical" value of the stress concentration factor due to the "defects" in the metal.

In Fig. 10 are shown two sets of curves, one for each of two different metals, and the upper three curves for each metal show the "theoretical" values of the stress concentration factor obtained by using the Neuber diagram alone.

Now it is a matter of general experience that values of the actual strength-reduction factor for metal parts are smaller than the values of stress concentration factor derived, as is the Neuber diagram, from a mathematical analysis based on the assumptions of the mathematical theory of elasticity, namely, the assumptions of homogeneity, isotropy, and Hooke's law. These assumptions are never perfectly realized in any common structural material, especially in metals composed of crystalline grains, and under any stress there is probably some inelastic yielding which tends to cut down the peaks of stress concentration. In his treatise (3) Neuber recognized this and proposed a formula to determine from the "theoretical" stress concentration factor an actual strength-reduction factor. Neuber's modifying formula is:

$$k' = 1 + \frac{k_t - 1}{1 + \sqrt{\rho'/\rho}} \quad \ldots\ldots (1)$$

where:

k' = the actual strength-reduction factor due to the notch,
k_t = the "theoretical" or "geometrical" stress concentration factor given by the Neuber diagram (Fig. 5),
ρ = the radius of curvature at the bottom of the notch, and
ρ' = some dimension of the "elementary structural unit" of the metal.

Evidently the "elementary structural unit" is a concept not used in conventional mechanics of materials. It may be thought of as the smallest individual block of the metal whose fracture will start a spreading crack in the metal under repeated stress.

In studying the use of Eq. 1, for each metal studied, a value of ρ' was found by trial and error which harmonized to a satisfactory degree the results of the use of the Neuber diagram and formula with the results of actual fatigue tests. This is the same kind of procedure as was followed for values of ρ_D, and the possible significance of ρ' is also considered in a later paragraph.

---

[4] The "unnotched" specimens tested actually have some stress concentration due to the turned down section of the specimen, but the stress concentration factor due to this cause is about 1.05, and this factor, being of the same order of magnitude as the variations between different fatigue results for nominally identical specimens, has been neglected in this paper.

TABLE III.—COMPUTED EFFECT OF "DEFECTS" IN STEEL ON ENDURANCE LIMIT OF UNNOTCHED SPECIMENS.

A small "defect" is assumed to be equivalent in weakening the metal under repeated stress to a semicircular notch with a radius ρ_D.

Diameter of Specimen, in.	1/8	1/4	1/2	1	1 3/4	1 7/8		1/8	1/4	1/2	1	1 3/4	1 7/8
S.A.E. 1020 STEEL, AS ROLLED							**S.A.E. 1035 STEEL, ANNEALED**						
Item							Item						
1 Endurance Limit of Unnotched Specimen (S_e), by Test, psi	34 000	32 000	28 900	28 200	..	28 200	19	35 000	34 000	31 500	..	..	..
2 ρ_D assumed for "Defect," in.	0.006	0.006	0.006	0.006	..	0.006	20	0.006	0.006	0.006	..	..	..
3 Half-diameter of Specimen, (a in Fig. 5), in.	0.0625	0.125	0.250	0.500	..	0.938	21	0.0625	0.125	0.250	..	..	..
4 $\sqrt{a/\rho_D}$	3.22	4.55	6.43	9.10	..	12.50	22	3.22	4.55	6.43	..	..	..
5 "Theoretical" Stress concentration Factor, from Neuber Diagram (Fig. 5)	2.30	2.59	2.78	2.89	..	2.95	23	2.30	2.59	2.78	..	..	..
6 Equivalent Radius (ρ') for "Structural Unit" of Metal, in., assumed to be	0.019	0.019	0.019	0.019	..	0.019	24	0.0014	0.0014	0.0014	..	..	..
7 $\sqrt{\rho'/\rho_D}$	1.78	1.78	1.78	1.78	..	1.78	25	0.485	0.485	0.485	..	..	..
8 Strength reduction Factor (k'); from Neuber Diagram, modified by Neuber Formula (Eq. 1)	1.47	1.57	1.64	1.68	..	1.70	26	1.88	2.07	2.12	..	..	..
9 Computed Endurance Limit for Unnotched Specimen, free from Defects = $S_e \times k'$, psi	50 000	50 200	47 500	47 400	..	48 000	27	65 600	70 500	66 800	..	..	..
S.A.E. 1035 STEEL, AS ROLLED							**S.A.E. X4130 STEEL, HEAT-TREATED**						
10 Endurance Limit of Unnotched Specimen (S_e), by Test, psi	39 000	39 000	35 000	34 400	..	34 400	28	75 400	69 800	65 000	63 600	63 600	..
11 ρ_D assumed for "defect", in.	0.006	0.006	0.006	0.006	..	0.006	29	0.006	0.006	0.006	0.006	0.006	..
12 Half-diameter for Specimen, (a in Fig. 5), in.	0.0625	0.125	0.250	0.500	..	0.938	30	0.0625	0.125	0.250	0.500	0.875	..
13 $\sqrt{a/\rho_D}$	3.22	4.55	6.43	9.10	..	12.50	31	3.22	4.55	6.43	9.10	12.10	..
14 "Theoretical Stress concentration from Neuber Diagram (Fig. 5)	2.30	2.59	2.78	2.89	..	2.95	32	2.30	2.59	2.78	2.89	2.93	..
15 Equivalent Radius (ρ') for "Structural Unit" of Metal, in., assumed to be	0.019	0.019	0.019	0.019	..	0.019	33	0.00068	0.00068	0.00068	0.00068	0.00068	..
16 $\sqrt{\rho'/\rho_D}$	1.78	1.78	1.78	1.78	..	1.78	34	0.113	0.113	0.113	0.113	0.113	..
17 Strength reduction Factor (k'); from Neuber Diagram, modified by Neuber Formula (Eq. 1)	1.50	1.57	1.64	1.68	..	1.70	35	2.15	2.41	2.57	2.67	2.71	..
18. Computed Endurance Limit for Unnotched Specimen, free from Defects = $S_e \times k'$, psi	58 500	61 200	57 500	57 800	..	58 400	36	162 000	168 000	167 000	169 000	173 000	..

This method of trial and error for finding values of ρ' and ρ_D means, of course, that the only thing demonstrated is that, using the Neuber diagram and formula, values of ρ_D and ρ' for the metals tested were found which gave results which agreed quite well with test results. However, even this gives promise of usefulness. Many more tests of other metals, and careful study of the relation of the values of ρ' and ρ_D with physical properties of the metals, such as grain size, dimensions of small surface irregularities, etc., must be made.

The results of the fatigue tests of unnotched specimens of different sizes may now be regarded as tests of specimens in which there are stress raisers. Assuming a value of ρ_D and of ρ' the "theoretical" stress concentration factor k_t and the strength reduction factor k' may be determined by using first the Neuber diagram, and then applying Eq. 1 to the value[5] of k_t. By trial and error, values of ρ' and ρ_D were found for each of the metals tested which gave strength-reduction factor k' which when multiplied by the endurance limits determined by test for different sizes of unnotched specimen gave a set of values which may be thought of as endurance limits for specimens of the metal which were free from inherent defects and resulting stress concentrations. These values for this ideal endurance limit were, as might be expected, nearly independent of the size of the specimen.

Table III shows the plan of carrying out the operations listed in the preceding paragraph. The values of ρ' and ρ_D are the values found, by trial and error, to give values of endurance limit for "flawless" specimens independent of size of specimen. These values are given in items 9, 18, 27, and 36 of Table III.

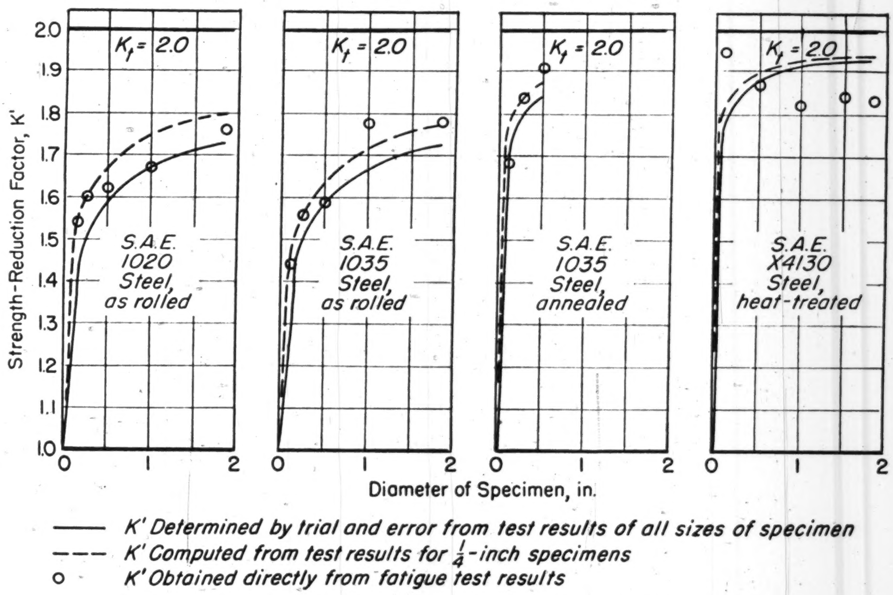


FIG. 11.—Values of Strength-Reduction Factor.

This use of the Neuber diagram, modified by the Neuber formula, to explain size effect in unnotched fatigue specimens and machine parts involves speculative thinking, but it is believed to be of enough promise to justify serious consideration and further testing.

COMPARISON OF STRENGTH-REDUCTION FACTORS COMPUTED BY THE NEUBER DIAGRAM AND FORMULA WITH THOSE SHOWN BY FATIGUE TESTS

In determining the strength-reduction factor to apply to the endurance limit of

---

[5] In applying Eq. 1 to determine k' for the unnotched specimens, the radius of the notch is to be taken as equal to ρ_D, and the formula becomes

$$k' = 1 + \left(\frac{k_t - 1}{1 + \sqrt{\rho'/\rho_D}}\right).$$

an unnotched specimen, or machine part, in order to compute the strength of the specimen, or part, with a given notch it is not necessary to know the value of ρ_D. If k' is the strength-reduction factor from endurance limit S_e obtained by test for unnotched specimen to S_n, the endurance limit for notched specimen, and if k'_u is the strength-reduction factor from endurance limit S_f of the "flawless" specimen to S_e then, $S_e \times k'_u = S_f$. It seems reasonable to assume that the strength-reduction factor due to notches and that due to "defects" together produce a strength reduction of $k' \times k'_u$ so that $S_n \times k' \times k'_n = S_f$. From these two equations $S_n \times k' = S_e$.

TABLE IV.—ENDURANCE LIMITS FOR NOTCHED SPECIMENS, COMPUTED FROM THE NEUBER DIAGRAM (FIG. 5), MODIFIED BY THE NEUBER FORMULA (EQ. 1).

Item	Diameter of Specimen, in.	⅛	¼	½	1	1¾	1⅞	Item	⅛	¼	½	1	1¾	1⅞
	S.A.E. 1020 STEEL, AS ROLLED								S.A.E. 1035 STEEL, ANNEALED					
1	Radius of Notch (ρ), in.	0.01	0.02	0.04	0.08	..	0.14	17	0.01	0.02	0.04	..	..	..
2	"Theoretical" Stress concentration Factor from Neuber Diagram	2.00	2.00	2.00	2.00	..	2.06	18	2.00	2.00	2.00	..	..	..
3	Equivalent Radius (ρ') for "Structural Unit" of Metal, in., assumed to be	0.019	0.019	0.019	0.019	..	0.019	19	0.0014	0.0014	0.0014	..	..	..
4	$\sqrt{\rho'/\rho}$	1.38	0.98	0.69	0.49	..	0.37	20	0.375	0.264	0.187	..	..	..
5	Strength reduction Factor (k'); from Neuber Diagram, modified by Neuber Formula	1.42	1.51	1.59	1.67	..	1.73	21	1.73	1.79	1.84	..	..	..
6	Endurance Limit for Unnotched Specimen (S_e), by test, psi.	34 000	32 000	28 900	28 200	..	28 200	22	35 000	34 000	31 500	..	..	..
7	Computed Endurance Limit for Notched Specimen = Se/k', psi.	24 000	21 200	18 200	16 900	..	16 000	23	20 200	19 000	17 100	..	..	..
8	Endurance Limit for Notched Specimen, by Test, psi.	22 000	20 000	17 800	17 200	..	16 000	24	21 000	18 500	16 500	..	..	..
	S.A.E. 1035 STEEL, AS ROLLED								S.A.E. X4130 STEEL, HEAT-TREATED					
9	Radius of Notch (ρ), in.	0.01	0.02	0.04	0.08	..	0.14	25	0.01	0.02	0.04	0.08	0.14	..
10	"Theoretical" Stress concentration Factor from Neuber Diagram	2.00	2.00	2.00	2.00	..	2.06	26	2.00	2.00	2.00	2.00	2.06	..
11	Equivalent Radius (ρ') for "Structural Unit" for Metal, assumed to be, in.	0.019	0.019	0.019	0.019	..	0.019	27	0.00068	0.00068	0.00068	0.00068	0.00068	..
12	$\sqrt{\rho'/\rho}$	1.38	0.98	0.69	0.49	..	0.37	28	0.260	0.185	0.131	0.093	0.070	..
13	Strength reduction Factor (k'); from Neuber Diagram, modified by Neuber Formula	1.42	1.51	1.59	1.67	..	1.73	29	1.79	1.84	1.88	1.92	1.94	..
14	Endurance Limit for Unnotched Specimen (S_e), by Test, psi.	39 000	39 000	35 000	34 400	..	34 400	30	75 400	69 800	65 000	63 600	63 600	..
15	Computed Endurance Limit for Notched Specimen = Se/k, psi.	27 500	25 200	22 000	20 500	..	19 800	31	42 100	38 000	34 600	33 200	32 700	..
16	Endurance Limit for Notched Specimen, by Test, psi.	27 000	25 000	22 000	19 300	..	19 300	32	38 600	37 300	35 800	34 600	34 800	..

In determining values of ρ' and ρ_D which would fit test results, it is then convenient to first determine ρ' from tests of unnotched and tests of notched specimens of different sizes before considering size effect in unnotched specimens.

Neuber (3), by the use of empirical methods, found for two different steels a value of 0.48 mm., or approximately

0.019 in. for ρ'. This value was tried out for the steels tested by the authors of this paper and was found to give good results for steels S.A.E. 1020, as rolled, and S.A.E. 1035, as rolled. For S.A.E. steel 1035, annealed, and for steel S.A.E. X4130 this value did not give good results, and by trial a value of 0.0014 in. for steel S.A.E. 1035, annealed, and a value of 0.00068 in. for S.A.E. X3140 steel were found satisfactory.

Table IV shows the steps in checking the agreement of computed and experimental values of endurance limit of notched specimens. Comparison of values in items 7 and 8, 15 and 16, 23 and 24, and 31 and 32 shows the agreement found. Figure 11 shows graphically the agreement found between computed and test values of k' for notched bars.

By trial and error a value of 0.006 in. for ρ_D was found to give satisfactory results in determining for all the steels tested the strength-reduction factor presumed to be present in unnotched specimens, due to inherent defects in the steels tested.

TABLE V.—VALUES OF ρ_D, THE RADIUS OF NOTCH WHOSE WEAKENING EFFECT EQUALS THAT OF THE INHERENT DEFECTS IN STEEL AND OF ρ' IN THE NEUBER FORMULA $k' = 1 + \left(\frac{k_t - 1}{1 + \sqrt{\rho'/\rho}}\right)$.

Steel	ρ_D in in. Found by trial and error to give results agreeing approximately with fatigue test results for all sizes of specimens tested	ρ' in in. Found by trial and error to give results agreeing approximately with fatigue test results for all sizes of specimens tested	ρ', in., Determined from Results of Fatigue Tests on Specimens with Diameters (in in.)				
			1/8	1/4	1/2[a]	1	1 7/8 or 1 3/4
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
S.A.E. 1020, as rolled	0.006	0.0190	0.0067	0.0089	0.0150	0.0190	0.0140
S.A.E. 1035, as rolled	0.006	0.0190	0.0160	0.0120	0.0193	0.0064	0.0111
S.A.E. 1035, annealed	0.006	0.0014	0.0025	0.00072	0.00038	...	...
S.A.E. X4130, heat treated	0.006	0.00068	0.00034	0.00049	0.00194	0.0050	0.0059

[a] *Sample Calculation for ρ':* Take the ½-in. specimen of S.A.E. 1035 steel as rolled. Then from item 9 in Table IV, $\rho = 0.04$ in. In the Neuber diagram (Fig. 5) $a = 0.25$ in. and $t = \rho = 0.04$ in. Then from the Neuber diagram, k_t: the theoretical stress concentration factor is found to be 2.00. From items 14 and 16 in Table IV the actual strength-reduction factor is $\frac{35\,000}{22\,000} = 1.59$. Then using Eq. 2, $\rho' = \rho\left(\frac{k_t - k'}{k' - 1}\right)^2 = 0.04\left(\frac{2.00 - 1.59}{1.59 - 1.00}\right)^2 = 0.0193$ in.

Physical Significance and Suggested Method of Estimating Values of ρ_D:

In column 4 of Table V is given the value of ρ_D which by trial was found to give uniform values of endurance limit for all sizes of specimens of each of the metals tested. The value of ρ_D then may be looked upon as the radius of a semi-circular notch which would cause as great strength reduction of the metal under repeated stress as do the inherent "defects" in the metal. The same value for ρ_D was found to fit fairly well the test results for all the steels tested. This value, 0.006 in., would be about the width of a fine scratch on the surface of the steel. This does not mean that the inherent defects in steel *are* fine surface scratches, it means the reduction of endurance limit of unnotched specimens as their size increases may be explained if we assume that there exist in commercial sound steel inherent defects (probably microscopic) which reduce the fatigue strength of the steel about as much as would a rather fine surface scratch. Furthermore this assumption is in harmony with test results (**6, 7**), which indicate that any polish finer than an ordinary good shop polish (say with 00 or 000 Emery cloth) will not add much to the fatigue strength of a test specimen or of a machine part.

The Application of the Neuber Diagram and Formula to Size Effect on Fatigue Strength of Steel Parts up to 2 in. Thick:

At the beginning of this section it seems well to emphasize again the limitations of any conclusions which may be drawn from the data and results herein presented. The tests made include no tests on specimens more than $1\frac{7}{8}$ in. in diameter, and, although the diameter-endurance limit diagrams (Fig. 7) "flatten out" at about $\frac{3}{4}$ in. in diameter, it does not seem safe to assume that specimens larger in diameter (or thickness) will withstand as high repeated stresses as the extrapolated diagram would indicate. This is discussed more fully in the next section.

The Neuber diagram concerns itself with the geometry of the shape of the specimen, and assumes, as do all formulas and diagrams based on the theory of elasticity, that the material is homogeneous and isotropic, and that Hooke's law holds. From that diagram is obtained a stress-concentration factor. Now for actual metals the strength-reduction factor corresponding to a notch is somewhat less than this stress-concentration factor. This is due in part to the fact that at regions of high stress concentration some inelastic yielding occurs and there is some adjustment of stress with a cutting down of high "peaks" of stress. This difference between stress-concentration factor and strength-reduction factor may also be due to the fact that at the root of a notch there exists a state of tri-axial stress and that the measure of structural damage may not be stress but distortion energy or, possibly, for brittle materials, strain (2). The Neuber formula (Eq. 1) modifies the stress concentration factor given by the Neuber diagram so that the use of both diagram and formula determines a true strength-reduction factor for the metal under consideration.

The dimension ρ' in the Neuber formula $k' = \dfrac{k_t - 1}{1 + \sqrt{\rho'/\rho}}$ was not obtained by direct measurement, but was determined by trial to be of such magnitude for a metal that its use in the Neuber formula gave for that metal fairly good agreement between the strength-reduction factor determined from the Neuber diagram modified by the Neuber formula and the strength-reduction factor determined directly by fatigue tests of notched and unnotched specimens of various sizes. That is, while the value of ρ' could not be directly measured, by trial and error a value was found for each steel tested which gave satisfactory results.

Table V gives values of ρ_D and ρ' determined by trial and error from test results of all sizes of specimens tested (columns 2 and 3). A glance at Figs. 1 and 2 suggests that the steels with large grain size have lower values of ρ' than those with small grain size.[6] Steels S.A.E. 1020, as rolled, and S.A.E. 1035, as rolled, show large sharp-pointed grains, suggesting that the rolling process may have broken up grains, *possibly* the original austenite grains. The structure of the S.A.E. 1035 annealed steel is a banded structure, and that of the heat-treated S.A.E. X4130 steel is fine-grained and uniform. The test data available do not seem to justify any attempt to determine a quantitative correlation between the value of ρ' and grain size.

By trial and error the value of 0.006

---

[6] In the case of the S.A.E. 1035 steel, annealed, (see Fig. 2) the grain structure is coarse in the ferrite bands, but the metal outside the ferrite bands, including the surface layers, has a fine-grained structure.

in. for ρ_D was found to give results which for all sizes of all the steels tested gave satisfactory results in determining the size effect on the endurance limit of unnotched bars. This determination is discussed in a subsequent section. It is suggested that in predicting size effect in steel bars *not greater than 2 in.* in diameter it may be tentatively used. Determining the value of ρ' by trial and error from a study of all specimens tested proved to be a tedious process, as well as one involving a large number of fatigue tests. From a series of fatigue tests of unnotched specimens of a given size and series of notched fatigue specimens of the same size a determination of the value of ρ' may be made as follows: Let S_e represent the endurance limit for unnotched specimens, S_n the endurance limit for notched specimens, k' the strength-reduction factor, k_t the "theoretical" stress-concentration factor obtained from the Neuber diagram, and ρ the radius in inches of the notch in the notched specimens. Then $k' = S_e/S_n$ and the Neuber formula is $k' = 1 + \left(\frac{k_t - 1}{1 + \sqrt{\rho'/\rho_1}}\right)$.

Then from the Neuber formula

$$\rho' = \rho\left(\frac{k_t - k'}{k' - 1}\right)^2 \quad \ldots\ldots(2)$$

TABLE VI.—VALUES OF k', THE STRENGTH-REDUCTION FACTOR FROM UNNOTCHED TO NOTCHED SPECIMENS.

Diameter of Specimen, in.	k' from Fatigue Tests	k'		k'		k'		k'		k'		k'	
		From Values of ρ' determined by trial to agree approximately with test results on all sizes of Specimen	Deviation from Values in (2) per cent	From Values computed from test results for ⅛-in. Specimens	Deviation from Values in (2) per cent	From Values computed from test results for ¼-in. Specimens	Deviation from Values in (2) per cent	From Values computed from test results for ½-in. Specimens	Deviation from Values in (2) per cent	From Values computed from test results for 1-in. Specimens	Deviation from Values in (2) per cent	From Values computed from test results for 1¾ and 1⅞-in. Specimens	Deviation from Values in (2) per cent
1	*2*	*3*		*4*		*5*		*6*		*7*		*8*	
						S.A.E. 1020 STEEL, AS ROLLED							
⅛	1.54	1.42	−7.8	1.54	0	1.52	−1.3	1.45	−5.8	1.42	−7.8	1.46	−5.2
¼	1.60	1.51	−5.6	1.63	+1.9	1.60	0	1.54	−3.7	1.51	−5.6	1.54	−3.7
½	1.62	1.59	−1.8	1.71	+5.5	1.68	+3.7	1.62	0	1.59	−1.9	1.63	+0.6
1	1.67	1.67	0	1.78	+6.6	1.75	+4.8	1.69	+1.2	1.67	0	1.70	+1.8
1⅞	1.76	1.73	−1.7	1.82	+3.4	1.80	+2.3	1.75	−0.6	1.73	−1.7	1.76	0
						S.A.E. 1035 STEEL, AS ROLLED							
⅛	1.44	1.42	−1.4	1.44	0	1.47	+2.1	1.42	−1.4	1.56	+8.3	1.49	+3.5
¼	1.56	1.51	−3.3	1.52	−2.6	1.56	0	1.51	−3.2	1.64	+5.1	1.57	+0.6
½	1.59	1.59	0	1.61	+1.3	1.64	+3.2	1.59	0	1.72	+8.2	1.65	+3.8
1	1.78	1.67	−6.4	1.69	−5.1	1.72	−3.4	1.67	−6.4	1.78	0	1.73	−2.8
1⅞	1.78	1.73	−2.8	1.75	−1.7	1.77	−0.6	1.73	−2.8	1.83	+2.8	1.78	0
						S.A.E. 1035 STEEL, ANNEALED							
⅛	1.67	1.73	+4.2	1.67	0	1.79	+7.2	1.84	+10.1	...	...	...	...
¼	1.84	1.79	−2.7	1.74	−5.4	1.84	0	1.88	+2.2	...	...	...	...
½	1.91	1.84	−3.7	1.80	−5.8	1.88	−1.6	1.91	0	...	...	...	...
						S.A.E. X4130 STEEL, HEAT-TREATED							
⅛	1.95	1.79	−8.2	1.95	0	1.82	−6.7	1.70	−12.8	1.65	−15.4	1.59	−18.4
¼	1.87	1.84	−1.6	1.96	+4.8	1.87	0	1.76	−5.9	1.72	−8.0	1.67	−10.7
½	1.82	1.88	+3.3	1.97	+8.2	1.90	+4.4	1.82	0	1.80	−1.1	1.74	−4.4
1	1.84	1.92	+4.3	1.98	+7.6	1.93	+4.9	1.86	+1.1	1.84	0	1.80	−2.2
1¾	1.83	1.93	+5.5	1.98	+8.2	1.94	+6.0	1.90	+3.8	1.88	+2.7	1.83	0

Values of ρ' were determined by this method based on the test results for each steel for each size of specimen tested.

These results are shown in Table V, columns 4 to 8 inclusive. In this table are also given the values of ρ' found by trial and error from a study of all fatigue test results for all sizes of each steel tested. The variation in values of ρ' is large. However, in the course of study of test results it became evident that a considerable variation in the value of ρ' caused a relatively slight variation in the value of k', the strength-reduction factor.[7]

Table VI shows values of k' determined both by the general trial and error method (column 3) and by values based on fatigue test results for different sizes of specimen (columns 4, 5, 6, 7, and 8). The deviation in per cent from the corresponding value of k' found directly from fatigue tests is also shown. Except from the values of k' determined from the tests of 1-in. and of $1\frac{3}{4}$ and $1\frac{7}{8}$-in. specimens, the deviations of value of k' from that given directly by fatigue tests of unnotched and notched specimens are not prohibitively large. The values of k' computed from the fatigue test results for $\frac{1}{4}$-in. specimens seemed the most satisfactory, in fact about as satisfactory as the values determined from the study of all test results (compare values in column 3 with those in column 5).

It is believed, then, that while no direct method has been found for determining the value of ρ' in the Neuber formula, that value may be determined with a fair degree of accuracy for steel bars not larger than 2 in. in diameter by fatigue tests of notched and of unnotched specimens. It seems also that tests of $\frac{1}{4}$-in. specimens may be expected to give satisfactory results, and this size of specimen can be tested in the ordinary rotating-beam fatigue testing machine.

To determine the endurance limits, notched and unnotched, for a given size specimen (or round part) from fatigue test results on another size specimen, it is assumed that size effect in unnotched specimens is due to inherent defects, probably microscopic, in steel, and that the weakening effect of these defects may be regarded as equivalent to that of a semi-circular notch with radius ρ_D. For steel, ρ_D may be taken as 0.006 in. Using the Neuber diagram to determine k_t for the unnotched specimen, and using the value of ρ' previously determined, find the strength-reduction factor k'_u from "flawless" unnotched specimen to actual unnotched specimen. Then if S_e is the endurance limit for the "unnotched" specimen, and S_f is the endurance limit for a "flawless" specimen of the same size,

$$S_e \times k'_u = S_f$$

It has been assumed that size effect in unnotched specimens is due to inherent defects in the steel. If this assumption is correct, the endurance limit for "flawless" steel may be expected to be independent of the size of the specimen. Items 9, 18, 27, and 36 in Table III show little variation in the value of S_f with size of specimen.

Having the value of S_f for a "known" specimen (a specimen whose endurance limits, notched and unnotched, are known), the value of S_f for an "unknown" specimen may be taken as equal to that of the "known" specimen. Now regarding the "unknown" unnotched specimen as having a notch with radius of 0.006 in., find the corresponding value of k_t from the Neuber diagram. Then apply the Neuber formula to obtain the strength-reduction factor, k'_u, for the "flawless" specimen of the same size as the "unknown" specimen. In this particular case the Neuber formula becomes:

---

[7] A similar statement can be made concerning variations in value of ρ_D.

$$k'_u = \frac{k_t - 1}{1 + \sqrt{\rho'/\rho_D}}$$

In the above formula ρ_D may be taken as 0.006 in. for steel and ρ' has already been determined for the metal from test results on the notched and the unnotched "known" specimens by the use of Eq. 2. Then endurance limit of the "unknown" unnotched specimen is S_f/k'_u. Since ρ' for the metal is known, the strength-reduction factor, k', from the endurance limit of the "unknown" unnotched specimen (S_f/k'_u) to the endurance limit of the "unknown" notched specimen may be computed by the use of the Neuber diagram and the Neuber formula, and the endurance of the "unknown" notched specimen determined.

A numerical solution of a problem illustrating the above procedure is given in the Appendix to this paper.

Size Effect in Specimens Larger than 2 in. in Diameter:

Several warnings have been given in this paper against using the methods and formulas herein developed for determining endurance limits of specimens (or bars) more than 2 in. in diameter. The reason for this is that some experiments (8) have shown endurance limits for specimens 6 or 7 in. in diameter much lower than would be predicted by the Neuber diagram, modified by the Neuber formula. In these tests other variables besides size were present, so that it is not sure that the low values of endurance limit were due to size effect alone. However, these test results make it unwise to extrapolate values obtained by the Neuber analysis to compute size effect on specimens with diameters greater than 2 in.

A purely speculative explanation is here offered for the falling off of fatigue strength for specimens larger than 2 in. in diameter. The "defects" assumed to be represented by radius ρ_D are small inherent defects in steel, presumably scattered at random throughout a piece. There may be occasional macroscopic defects in any piece of steel, and if such a defect occurs within the critical region of a specimen or a part it may lower the fatigue strength appreciably. The probability of such a macro-defect occurring in or near a critical region in the surface of the piece would be some function of size of piece, probably a function increasing more rapidly than the first power of the diameter.

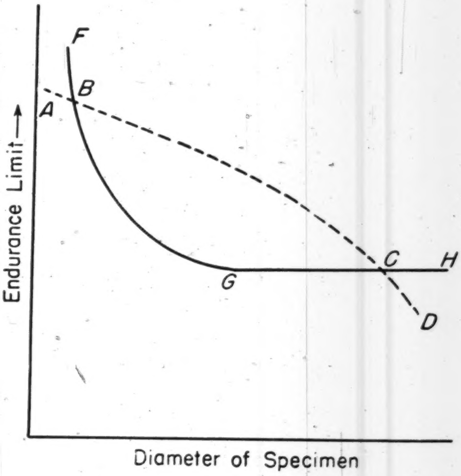


FIG. 12.—Schematic Diagram of the Speculative Hypothesis that the Probability of the Occurrence of Large Defects may be the Controlling Factor in Certain Ranges of Size of Specimen.

Figure 12 shows this speculative theory in diagram. The line *FBGCH* shows the variation of endurance limit as given by the Neuber diagram - Neuber formula treatment. The line *ABCD* shows (speculatively) the variation of endurance limit due to the increased probability of macro-defects becoming effective. From *A* to *B* the "probability" may rule, owing to the fact that for very small specimens a macro-defect may be large enough to change seriously the section modulus of a cross-section some distance from the minimum diameter. From B to C the Neuber diagram modified by the Neuber formula would determine fatigue failure, while beyond C the increasing probability of macro-defects coming in critical surface regions would control.

This question of the fatigue strength of pieces more than 2 in. in diameter will require a testing program far more extensive than any size-effect program hitherto undertaken, but this is an important problem in structural and machine design, and it is believed that the expense would be justified.

Size Effect in Other Metals:

Very little work has been done on size effect on the fatigue properties of metals other than steel. A few tests on duraluminum (9) show very little size effect between 0.175 in. diameter and 0.41 in. diameter, a range of size within which steel shows a well-marked size effect. A few tests of cast iron, made at the University of Illinois, show a slight size effect from variation from 0.25 in. diameter to 1 in. diameter. Much further experimentation in the field of cast iron, special steels, and non-ferrous metals is needed.

Acknowledgments:

The work of the past year could not have been carried on had it not been for the generous financial support of the Research Committee of the American Society for Testing Materials, and grateful acknowledgment is here made for grants from the Society's research fund.

Appreciation is expressed to W. H. Bruckner, Research Assistant Professor of Metallurgical Engineering at the University of Illinois, for annealing the steel S.A.E. 1035 and preparing the photomicrographs, as well as general advice on metallurgical matters, and to Mr. O. M. Sidebottom, Special Research Assistant in Theoretical and Applied Mechanics, University of Illinois.

The work in the Talbot Laboratory was carried on as a part of the regular work of the University of Illinois Engineering Experimental Station, Dean M. L. Enger, Director, and of the Department of Theoretical and Applied Mechanics, Prof. F. B. Seely, Head.

REFERENCES

(1) H. F. Moore and D. Morkovin, "Progress Report on the Effect of Size of Specimen on the Fatigue Strength of Three Types of Steel," *Proceedings*, Am. Soc. Testing Mat., Vol. 42, p. 145 (1942).

(2) H. F. Moore and D. Morkovin, "Second Progress Report on the Effect of Size of Specimen on the Fatigue Strength of Three Types of Steel," *Proceedings*, Am. Soc. Testing Mats., Vol. 43, p. 109 (1943).

(3) H. Neuber, "Kerbspannumgslehre," Julius Springer, Berlin, 1937.

(4) O. J. Horger and H. R. Neifert, Discussion on Size Effect, *Proceedings*, Am. Soc. Testing Mats., Vol. 43, pp. 121 and ff. (1943).

(5) J. O. Almen, "Shot Blasting to Increase Fatigue Resistance", *Transactions*, Soc. Automotive Engrs., Vol. 51, No. 7, July, 1943, p. 248.

(6) H. F. Moore and J. B. Kommers, "An Investigation of the Fatigue of Metals," p. 108, Bulletin 124, Engineering Experiment Station, University of Illinois.

(7) H. F. Moore and D. Morkovin, "Second Progress Report on the Effect of Size of Specimen on the Fatigue Strength of Three Types of Steel," *Proceedings*, Am. Soc. Testing Mats., Vol. 43, pp. 109–124, especially p. 123 (1943).

(8) O. J. Horger and H. R. Neifert, "Fatigue Strength of Machined Forgings 6 to 7 in. in Diameter," *Proceedings*, Am. Soc. Testing Mats., Vol. 39, p. 723 (1939).

(9) Research Committee on the Fatigue of Metals, 1941 Report, *Proceedings*, Am. Soc. Testing Mats, Vol. 41, pp. 133–150, especially Fig. 8, p. 144 (1941).

APPENDIX

Computation of Endurance Limits, of Unnotched and of Notched Specimens of S.A.E. 1020 Steel, 1 in. in Diameter from Fatigue Test Results on Specimens of the Same Steel $\frac{1}{4}$ in. in Diameter, Notched and Unnotched.

This illustrative computation is taken from data given in Tables III and IV. The value determined in this computation for ρ', and consequently values determined for S_f and for various strength-reduction factors, differ somewhat from corresponding values in Tables III and IV. However, even with the large difference in values of ρ' (0.019 in. in Table IV, 0.0089 in. in this computation) the end results, the endurance limit for a 1-in. specimen unnotched and for a 1-in. specimen notched check fairly well with values determined by fatigue tests,—in fact they check about as well as do the computed values in Table IV.

Radius of semicircular notch in $\frac{1}{4}$-in. specimen	0.02 in.
“ “ “ “ “ 1-in. “	0.08 in.
Endurance Limit for $\frac{1}{4}$-in. unnotched specimen, by test	32 000 psi.
“ “ “ $\frac{1}{4}$-in. notched “ “ “	20 000 psi.
k', Strength-reduction factor from unnotched to notched $\frac{1}{4}$-in. specimen	1.6
k_t, “Theoretical” stress concentration factor, from Neuber diagram; ($a = 0.125$ in.; $\rho = 0.02$; $t = \rho$)	2.00
ρ' for the metal from Eq. 2, ($\rho = 0.02$; $k_t = 2.00$; $k' = 1.6$)	0.0089 in.
Regarding unnotched $\frac{1}{4}$-in. specimen with inherent “defects” as equivalent to a $\frac{1}{4}$-in. specimen with a semicircular notch with radius of 0.006 in., the “theoretical” stress concentration factor, from the Neuber diagram ($a = 0.125$ in.; $\rho = 0.006$ in.; $t = \rho$) is	2.59
Strength-reduction factor, “flawless” $\frac{1}{4}$-in. specimen to unnotched $\frac{1}{4}$-in. specimen, by Neuber's formula ($\rho = 0.006$ in.; $\rho' = 0.0089$ in.; $k_t = 2.59$)	1.72
S_f, Endurance limit for “flawless” specimen of S.A.E. 1020 steel. This is the same for all sizes and is equal to 1.72 × 32 000	55 000 psi.
“Theoretical” stress concentration factor for 1-in. specimen, unnotched but with “defects”, from Neuber diagram ($a = 0.5$ in.; $\rho = 0.006$ in.; $t = \rho$)	2.89
Strength-reduction factor from “flawless” 1-in. specimen to unnotched 1-in. specimen, by Neuber's formula ($\rho = 0.006$ in.; $\rho' = 0.0089$ in.; $k_t = 2.89$)	1.85
Endurance limit for 1-in. unnotched specimen = 55 000/1.85	29 700 psi.
“ “ “ “ “ “ , by test	28 200 psi.
Deviation of computed value = 100 × (29 700 − 28 200)/28 200	+5.3 per cent
Theoretical stress concentration factor for 1-in. notched specimen from Neuber diagram ($a = 0.500$; $\rho = 0.08$ in.; $t = \rho$)	2.00
Strength-reduction factor for 1-in. specimen, notched to unnotched by Neuber formula ($\rho = 0.08$ in.; $k_t = 2.00$; $\rho' = 0.0089$ in.)	1.75
Endurance limit for 1-in. specimen, notched = 29 700/1.75	17 000 psi.
“ “ “ “ “ , by test	17 200 psi.
Deviation of computed value = 100 × (17 000 − 17 200)/17 200	−1.2 per cent

DISCUSSION

Mr. R. E. Peterson.[1]—The tests described in the paper are of special interest, particularly those where bright annealing was used. I believe that this is the first time that bright annealing has been used with a series of diameters of specimens.

The authors state that bright annealing disposes of the residual stress variable. It also disposes of any cold working effect due to machining. I have been concerned about such a variable for some time, and it is an important step to have a series of tests with this variable not present.

In that connection, I want to ask the authors if it is possible to make tests of bright annealed 2-in. diameter specimens without stress concentration. The reason I am asking is that if you compute the 2-in. diameter notched concentration factor using the $\frac{1}{2}$-in. diameter endurance limit value as a basis, you get a factor larger than the theoretical. A more reasonable factor would be obtained if the endurance limit of the bright annealed 2-in. diameter unnotched specimens would be lower than the $\frac{1}{2}$-in., being different in this respect from the series of specimens not bright annealed.

With regard to the defects and their explaining the results for unnotched pieces, that may be a possibility in the heat-treated pieces.[2] It does not seem so plausible for the other materials, S.A.E. 1020 and 1035 steel, and I believe that the results for these materials might be explained in a simpler way.

Neuber's analysis for notched pieces is equivalent to assuming (in the accompanying Fig. 1) that failure occurs when the endurance limit is reached at a distance ρ' beneath the surface. We can make the same assumption for unnotched specimens in bending, using the axial test value of endurance limit as a basis, resulting in the following formula:

$$S_e' = \frac{S_e}{\left(1 - \frac{2\rho'}{d}\right)}$$

where:

S_e' = endurance limit of bending specimen,

S_e = endurance limit of direct stress specimen,

ρ' = Neuber distance beneath surface, and

d = diameter of specimen.

This is a hyperbolic relation and results in an increase of endurance limit of small diameter specimens as shown in the paper. A value of $\rho' = 0.009$ in. appears to fit the data for S.A.E. 1020 and 1035 steel fairly well. For the previously published data by Moore and Jordan[3] on S.A.E. 1020 steel a value of $\rho' = 0.004$ in. seems to fit quite well.

For S.A.E. 1020 steel, it is of interest to point out the large difference in percentage increase in endurance limit for small unnotched specimens as shown in the accompanying Fig. 2, lot A showing only about one fourth the percentage increase of lot B. Looking over the published data on these two lots does not seem to provide a reason for the difference, and I should like to ask the authors if they have any ideas along this line. It would appear to be a basic point which needs to be clarified; otherwise attempts to tie in with grain size or other structural dimensions cannot, seemingly, be entirely satisfactory.

---

[1] Manager, Mechanics Div., Westinghouse Research Labs., Westinghouse Electric and Manufacturing Co., East Pittsburgh, Pa.

[2] E. S. Davenport, E. L. Roff, and E. C. Bain "Microscopic Cracks in Hardened Steel," *Transactions*, Am. Soc. Metals, Vol. 22, p. 289 (1934).

[3] H. F. Moore and R. L. Jordan, "Stress Concentration in Steel Shafts with Semi-Circular Notches," *Proceedings*, Fifth International Congress for Applied Mechanics, p. 188, John Wiley & Sons, Inc., New York, N. Y. (1939).

One other point—very small unnotched specimens do not continue to increase in endurance limit; in other words, a $\frac{1}{8}$-in. diameter specimen may show the same endurance limit as a $\frac{1}{4}$-in. diameter specimen. I have thought that the actual number of grains in the piece may be introducing an effect. We expect, of course, greatly reduced values for single crystals and specimens consisting of several grains, but some tests by Ziegler[4] show that we might expect reduced values even when the cross section consists of, say, a hundred grains. I would appreciate the authors' views on the effect mentioned.

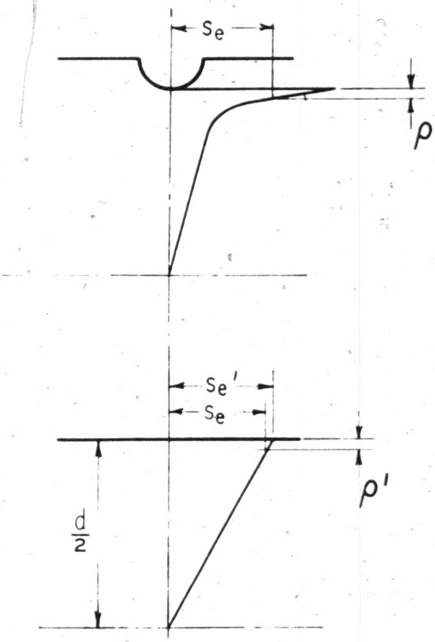


Fig. 1.—Gradient Effect in Notched and Unnotched Pieces.

In conclusion, I consider this an extremely interesting report and hope we can have more like it. It certainly is very appropriate as an A.S.T.M. Research Committee activity since if we get a variety of endurance limits from conventional unnotched specimens, depending on size, it means that we need plenty of light when comparing data and when considering standardization.

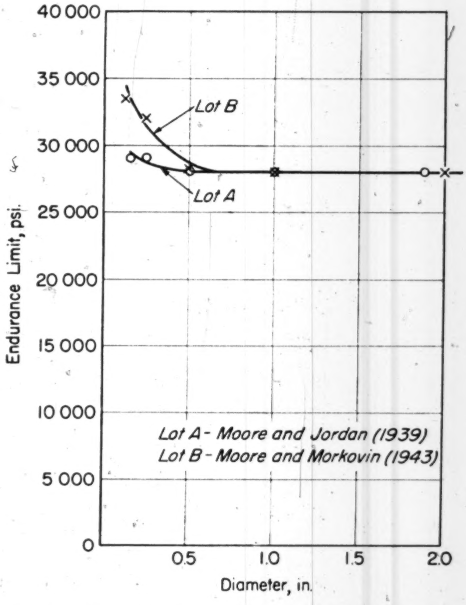


Fig. 2.—Fatigue Tests of Unnotched Specimens, SAE 1020.

MR. H. F. MOORE.[5]—I am very glad that Mr. Peterson added another promising method of approach. Couldn't it be made to work for S.A.E. 4130?

MR. PETERSON.—No, but I believe your defect theory may have some application for S.A.E. 4130, a heat-treated material which may show microscopic "defects" in the martensite. I do not believe it is necessary that the same theory fit different materials if it should turn out that failure is influenced by special factors in some cases. On the other hand, I am not suggesting that the problem can be answered completely at this time; what we need most of all is more work and data of the kind provided by the A.S.T.M. Research Committee.

---

[4] N. Ziegler, "Large Iron Crystals, Their Production and Some of Their Properties," *Transactions*, Am. Inst. Mining and Met. Engrs., Vol. 90, p. 209 (1930).

[5] Research Professor of Engineering Materials, Emeritus, University of Illinois, Urbana, Ill.

MR. MOORE (*author's closure, by letter*).—Mr. Peterson's proposed explanation of size effect, based on the assumption that the "true" endurance limit stress is reached at some distance below the surface is well worth further study. In his discussion he uses the symbol ρ' for that distance, but, to distinguish it from the ρ' constant in the Neuber formula, that distance below the surface will be designated by h in this closure. Then the formula suggested by Mr. Peterson becomes $S'_e = \frac{S_e}{(1 - 2h/d)}$.

This equation proposed by Mr. Peterson, if it can be applied to notched specimens as well as unnotched specimens, requires but one constant h to be determined rather than the two constants ρ' and ρ_D required in the method outlined in the Third Progress Report on Size Effect. Moreover the physical concept of h, a depth below the surface, and the starting of a crack there while the *stress* at the surface was still higher than the stress where the crack formed, on account of crystalline weakness, or other source of weakness, at that depth, —this concept is, I believe, easier to grasp than the concepts of ρ' and ρ_D in the method outlined in the Third Progress Report on Size Effect.

It is to be hoped that before the 1945 Annual Meeting of this Society the method proposed by Mr. Peterson may be tried out to see whether it can be made to fit available test results as well as does the application of the Neuber analysis made in the Third Progress Report on Size Effect.

In regard to Mr. Peterson's question about tests of 2-in. specimens of bright-annealed S.A.E. 1035 steel, I regret to state that owing to the shortage of help in the Talbot Laboratory it has not been possible as yet to machine 2-in. specimens and make the necessary tests.

Mr. Peterson asks for an explanation of the variation in size effect for S.A.E. 1020 steel shown by a comparison of the Moore-Jordan 1939 fatigue test results and the Moore-Morkovin 1943 results. The 1939 test specimens of S.A.E. 1020 steel were stress relieved at 450 F. for periods varying from ½ hr. to 2 hr., depending on size; the 1943 test specimens were tested as rolled. In the case of the 1943 specimens care was taken to have the inner critical fiber of each size of specimen at approximately the same distance from the axis of the bar from which the specimens were cut; this was not the case for the 1939 specimens. The 1939 specimens of S.A.E. 1020 steel showed a higher ratio of yield strength to tensile strength than did the 1943 specimens. The statement of these comparative data is about all the answer I can give to Mr. Peterson's question.

Mr. Peterson suggests that the increase of computed endurance limit with decrease in diameter of specimen may not continue below some critical size, and suggests an approach (even if it be a remote approach) to single-crystal conditions as a reason for expecting such a reversal of tendency. It does not seem unreasonable to assume such an action. Apparently, if such an optimum size exists it was not reached in the tests reported in the Third Progress Report on Size Effect, and this suggests that not only are tests of still larger specimens desirable, but that tests of still smaller specimens might also be well worth while.

REPORT OF JOINT RESEARCH COMMITTEE
ON
EFFECT OF TEMPERATURE ON THE PROPERTIES OF METALS
PROGRESS REPORT TO THE SPONSOR SOCIETIES

During the past year, the Joint Research Committee on Effect of Temperature on the Properties of Metals, under the sponsorship of The American Society of Mechanical Engineers and the American Society for Testing Materials, held one meeting on December 2, 1943, in New York, N. Y. A second meeting will be held in June, 1944, in New York, N. Y., prior to the presentation of this report at the Annual Meeting of the A.S.T.M. Several meetings of project committees have been held during the year.

In addition, the committee sponsored a Session on Graphitization of Steel Piping during the Annual Meeting of The American Society of Mechanical Engineers in New York, N. Y., on December 2, 1943, comprising the following papers:

"Graphitization Caused by Testing Conditions on Carbon-Molybdenum Tubular Creep-Test Specimens," by H. J. Kerr and F. Eberle,

"Carbide Instability of Carbon-Molybdenum Steel Piping," by R. W. Emerson,

"A Possible Means of Avoiding Local Graphitization of Steels in Service at Elevated Temperatures," by G. V. Smith and R. F. Miller, and

"Report on High-Temperature Pipe Weld Investigation," by Herman Weisberg.

The four papers and the discussion have been published by the A.S.M.E. in a special compilation, dated April, 1944, under the title "Graphitization of Steel Piping."

Finances:

There appears in Table I a summary of the administration of committee funds during the period from June 1, 1943, to June 26, 1944.

Organization and Membership:

No changes in organization or membership have taken place during the year.

Research Projects:

Project No. 18 on Effect of Variables on the High-Temperature Properties of Metals (H. W. Gillett, chairman).—During the year, the completed work that had not as yet been reported has been studied and arranged into a Third Progress Report, which appears in Appendix I.

Project No. 25 on Comparison of Short-Time Test Methods (J. S. Worth, chairman).—This study has now been completed, and the final report appears in Appendix II.

Project No. 29 on Stability of Steels as Affected by Temperature (J. J. Kanter, chairman).—This project was appointed at the June, 1943, meeting to consider problems arising from the instability of structure in steels for high-temperature services. A welded joint failure occurring at the Springdale Station of the West Penn Power Co. in January, 1943, led to the establishment of this project. The subject of particular, immediate concern is the graphitization of carbon and carbon-molybdenum steel used in high-temperature, high-pressure piping systems.

The membership of Project No. 29 is as follows:

J. J. Kanter (chairman),
J. W. Bolton,
Sabin Crocker,
R. W. Emerson,
A. J. Herzig,
S. L. Hoyt,
H. J. Kerr,
Don McCutcheon,
R. F. Miller,
N. L. Mochel,
E. L. Robinson,
S. H. Weaver,
J. S. Worth, and
A. E. White.

A meeting of Project No. 29 was held on October 21, 1943, in Chicago, Ill., at the Metal Congress attended by representatives of the joint project on investigation of the piping aspect of the graphitization problem sponsored by the Edison Electric Institute and the Association of Edison Illuminating Companies. A broad range program established by E.E.I.-A.E.I.C. to determine practical controls on the graphitization effects was reviewed. It was suggested that the joint committee might be very helpful in the broad range program by establishing physical properties, specifications, and working stresses around the materials and practices which result from the E.E.I.-A.E.I.C. researches sponsored at Battelle Memorial Institute.

At this meeting, the many evidences produced to justify the conclusion that graphitization occurs in hypo-eutectoid steels at superheated steam service temperatures were reviewed. Project No. 29 resolved to accept, as having been adequately demonstrated, that a constituent, essentially graphite, develops. It was also observed at this meeting that normal steel, having McQuaid-Ehn grain size of 1 to 5, appears to resist graphitization to a greater degree than aluminum-killed steel having a finer grained ferrite. Studies to clarify the effect of stress upon the pearlite-spheroidite-graphite history of steel subjected to exposure at subcritical temperatures were recommended.

At the December, 1943, meeting of the joint committee, a progress report based on the October meeting was presented. A resolution appropriating funds for initiating some investigation along the lines recommended on the graphitization problem was passed, contingent upon the location of institutional facilities which might be engaged. A canvass has failed to locate, under present stringent conditions, any available suitable location where the work might be carried out. Suggestions that work be done cooperatively for the joint committee by interested private laboratories was overruled on the grounds that such facilities were too far taxed under war conditions for such an undertaking.

TABLE I.—SUMMARY OF RECEIPTS AND EXPENDITURES OF COMMITTEE FUNDS.

Balance as of May 31, 1943, shown in 1943 Report			$9957.18
	RECEIPTS		
1943			
September	Interest on funds (10/1/42 to 9/30/43)		35.79
			$9992.97
	EXPENDITURES		
1943			
July	University of Michigan (Project No. 25)	$500.00	
1944			
January	National Process Co. (Printing Piping Papers)	140.01	
April	Flowers Photo. Engraving Co. (Engraving Piping Publication)	300.00	
June	Battelle Memorial Institute (Project 18)	398.38	
	Total Expenditures		$1338.39
Balance on hand, June 26, 1944			$8654.58

Respectfully submitted on behalf of the Joint Research Committee,

N. L. MOCHEL,
Chairman.

H. J. KERR,
Vice-Chairman.
J. W. BOLTON,
Secretary.

APPENDIX I

STUDY OF EFFECTS OF VARIABLES ON THE CREEP RESISTANCE OF STEELS

(Project No. 18)

Prepared by H. C. Cross and W. Simmons

Third Report Covering a Sponsored Research Project Carried Out at Battelle Memorial Institute

Synopsis

This progress report shows results of creep tests at 850 F. on a silicon-killed steel, a silicon-aluminum-killed steel, and an aluminum-killed nonaging steel, a rimmed carbon-molybdenum steel, and on plain carbon and carbon-molybdenum weld metal. A test was also made on a silicon-killed plain carbon steel obtained from England and for which relatively poor creep resistance had been shown.

All materials except the weld metal were heat treated to produce fine- and coarse-grain structures for comparison of their relative creep resistance and to determine the effect of different deoxidation practices.

A 0.14 per cent carbon silicon-killed steel was relatively insensitive as regards creep resistance to different heat treatments and cooling rates producing various austenite and ferrite grain sizes, but a 0.17 per cent carbon silicon-aluminum-killed steel showed much better creep resistance when coarsened and air cooled, with faster creep rates resulting from slower cooling from the coarsening temperature. For both steels, a heat treatment producing refinement of the austenite grain size tended to obliterate the effects of a previous coarsening treatment.

Air cooling after coarsening did not produce good creep resistance in an aluminum-killed nonaging steel, but the faster water quenching produced a very low rate of creep.

The addition of molybdenum to rimmed steel improves creep resistance as when added to killed steels. Little further improvement resulted from coarsening.

Experiments indicated that the British steel E was improved by coarsening, but not so much as expected, possibly because of its low silicon content.

Plain carbon and carbon-molybdenum weld metal was indicated equal or better in creep resistance to wrought steel of the same composition heat treated to optimum creep resistance.

Two previous reports have been presented to the sponsor societies on this subject.[1,2] It was shown that different heat treatments which produced various austenite and ferrite grain sizes, also resulted in marked effects on the creep resistance at 750 to 950 F. of pure iron and carbon steels up to about 0.60 per cent carbon. Heat treatment producing coarsening of these materials improved their creep resistance generally as compared with the materials in the fine-grain condition.

Steels melted using various deoxidation practices were tested. Silicon-killed steel shows consistently better creep resistance than rimmed steel as heat treated to produce both fine- and coarse-grain material. In S.A.E. 1015 steels, silicon-killed steels were superior to silicon-aluminum- and aluminum-killed steels either fine grain or slow cooled from the coarsening temperature used, while steels air cooled from the coarsening temperature showed similar creep resistance. All steels showed improvement in creep resistance when air cooled from temperatures producing coarse-grain material as compared with steels air cooled from temperatures to produce fine-grain material with the greatest improvement resulting in the aluminum-treated steels which, in the fine-grain condition, were considerably poorer than the silicon-killed steels.

The task of Project No. 18 is to attempt to unearth the cause of variations in creep behavior, so that by understanding of and application of the correct principles, creep behavior may be predictable and controlled.

On the basis of the work previously reported, the hypothesis was advanced that it was the absence or presence of inclusions of various types and compositions whose size, mode, and degree of dispersion changed with the various heat treatments which produced such large differences in creep resistance of the various irons and steels tested.

The present great strides being made in the development of alloys for service at temperatures of 1200 to 1600 F., which have been shown to be largely of the precipitation-hardening type, lend additional credence to the belief that a similar type of effect can take place in plain carbon and low-alloy steels. It is easily possible that submicroscopic nonmetallic particles, as well as carbides, might have a slip-interference effect producing creep resistance. Silicon-killed steel which has good creep resistance may contain such material, while a rimmed steel with its freedom from silicon and aluminum in any appreciable amount may not have present sufficient material of a submicroscopic, slip-preventing nature, which lack would account for its poor creep resistance.

Obviously, different types of soluble nonmetallic material will have different solubilities, different temperatures and times of saturation of the solvent, and different rates and modes of precipitation on cooling. It follows that for the various steels there may be critical cooling rates. It might turn out that an attempt to produce good creep behavior by coarsening (solubility treatment) and air cooling (precipitation treatment) would fail in the case of some steels. It might also fail in larger sections of steels in which good creep resistance was produced in smaller sections.

The observed phenomena fit in quite well with the hypothesis except in the case of the British acid open-hearth

---

[1] H. C. Cross and J. G. Lowther, "First Progress Report on Study of Effects of Manufacturing Variables on the Creep Resistance of Steels," *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 149 (1938).

[2] H. C. Cross and J. G. Lowther, "Second Progress Report on Study of Effects of Variables on the Creep Resistance of Steels," *Proceedings*, Am. Soc. Testing Mats., Vol. 40, p. 125 (1940).

steel E,[3] with 0.19 per cent carbon, 0.40 manganese, 0.08 silicon, 0.04 sulfur, 0.051 phosphorus, with no aluminum added, which showed poor creep resistance as normalized from 1740 F. It would appear that this steel should act like the usual silicon-killed steel. A sample of this steel is available for study.

TABLE I.—CHEMICAL COMPOSITION OF THE STEELS TESTED.

Steel Identification and Deoxidation Practice	Chemical Composition, per cent						
	Carbon	Manganese	Silicon	Sulfur	Phosphorus	Molybdenum	Aluminum Addition
5247, silicon-killed	0.14	0.48	0.18^a	0.03	0.014	. . .	
5280, silicon-aluminum killed	0.17	0.48	0.16^b	0.03	0.020	. . .	*b*
35561, aluminum-killed, nonaging	0.08	0.36	0.006	0.025	. . .	. . .	*c*
7666, carbon-molybdenum rimmed core	0.06	0.33	0.017	. . .	. . .	0.58^d	. . .
7666, carbon-molybdenum rimmed skin	0.06	0.32	0.007	. . .	. . .	0.57^d	. . .
GBE, silicon-killed	0.19	0.40	0.08	. . .	. . .	. . .	. . .
Weld metal A	0.12	0.66	0.24	. . .	. . .	. . .	. . .
Weld metal C	0.12	0.52	0.23	. . .	. . .	0.48	. . .
Weld metal D	0.14	0.44	0.12	. . .	. . .	0.59	. . .
Weld metal F	0.13	0.66	0.18	. . .	. . .	0.46	. . .

ALUMINUM, ALUMINA, AND GAS CONTENTS

	Carbon	Silicon	Residual Aluminum	Al_2O_3	Total Aluminum	O_2	H_2	N_2
Rimmed Steel (RI)	0.06	nil				0.018	0.00016	0.006
British Steel "E"	0.19	0.08	0.001	0.002		0.009	0.00014	0.002
Silicon-killed steel 5247	0.14	0.18	0.001	0.002		0.008	0.00009	0.007
Silicon-aluminum killed steel 3194 (1 lb. Al per ton)	0.15	0.16	0.001	0.002				
Aluminum-killed steel 5229 (2 lb. Al per ton)	0.15	0.02	0.014	0.010				
Aluminum-killed nonaging steel 35,561 (2.8 lb. Al per ton)	0.08	0.006	0.025	0.005	0.033^e			

NOTE: The above values for aluminum, and alumina were determined by The National Tube Co. methods briefly summarized below. The gas contents were determined at Battelle by the vacuum fusion method.

Determination of Soluble Aluminum:

The analysis is made in 5 steps, involving (1) solution of the sample in dilute H_2SO_4, (2) a separation with SO_2 and ammonia at pH 4.5 to remove the bulk of the iron, (3) a separation by electrolysis over a mercury cathode to remove the balance of the iron, (4) precipitation of the aluminum with 8-hydroxyquinoline, and (5) titration of the aluminum hydroxyquinolate with standard potassium bromate and sodium thiosulphate solutions.

Determination of Alumina (Al_2O_3):

The analysis consists of solution of a 50-g. sample in dilute H_2SO_4. The insoluble residue containing the Al_2O_3 is filtered, ignited, silica removed, and fused in pyrosulfate. The Al and Fe are precipitated with ammonia, fumed with $HNO_3 - H_2SO_4$, and the procedure completed from step (3) above.

[a] 10 lb. of 50 per cent ferrosilicon added per ton as ladle addition.

[b] Heat finished with 0.16 per cent silicon plus 2 lb. per ton of aluminum to produce fine grain.

[c] Heat finished with aluminum addition to ladle of 2.8 lb. per ton. Total aluminum, 0.033 per cent by analysis.

[d] Carbon-molybdenum rimmed steel made by addition of 60 per cent ferromolybdenum to ingot during teeming of rimmed steel.

[e] Inland Steel Co. determination.

The work herein reported details further studies of the proposed precipitation hypothesis. All of the work planned has not been completed because personnel and testing equipment have been diverted to direct war effort.

To study solubility effects and critical rates of cooling, some tests have been made on two S.A.E. 1015 steels formerly studied and on an aluminum-killed nonaging steel. One of the S.A.E. 1015 steels was silicon-killed and the other was silicon-aluminum killed (2 lb. aluminum per ton). The nonaging steel was aluminum-killed (2.8 lb. aluminum per ton).

Other tests have been made to determine the effect of adding molybdenum to a rimming steel and the response of this rimmed carbon-molybdenum steel to the usual type of coarsening treatments previously used on the plain carbon steels. It seemed of interest to determine whether the addition of molybdenum produced an effect on creep resistance which would overshadow the effects of finishing practice observed in plain carbon steels.

---

[3] C. H. M. Jenkins, H. J. Tapsell, G. A. Mellor, and A. E. Johnson, "Some Aspects of the Behavior of Carbon and Molybdenum Steels at High Temperatures," *Transactions*, Chem. Eng. Conference of the World Power Conference (London), Vol. 1, pp. 122-162 (1936).

The British steel E has been studied further in an effort to improve its creep resistance by heat treatment.

Some plain-carbon and carbon-molybdenum weld metal specimens have been tested in creep for comparison of their properties with wrought steel of the same composition. These tests are of interest because of the extreme fine grain of the weld metal.

STEELS TESTED

Table I shows the steels tested, their chemical composition, and some details of the deoxidation practice used in their manufacture.

The S.A.E. 1015 steels, heats 5247 and 5280, supplied by the National Tube Co., were previously tested and described.[2] They were melted similarly except for the final additions of ferrosilicon for heat 5247 and ferrosilicon and aluminum for heat 5280.

The aluminum-killed nonaging steel heat 35561 was supplied through the courtesy of J. H. Nead and the Inland Steel Co. as a 4 by 4-in. billet taken from ingot No. 10 of the heat. The heat was finished with an aluminum addition to

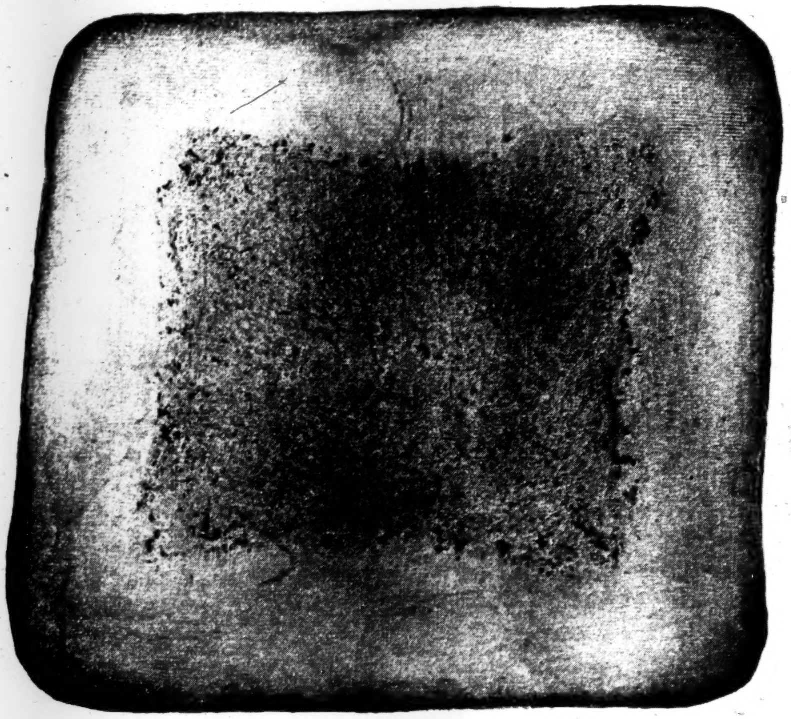


FIG. 1.—Macroetched Section of Rimmed Carbon-Molybdenum Steel Billet. 0.06 per cent carbon, 0.33 per cent manganese, 0.017 per cent silicon, 0.57 per cent molybdenum.

the ladle of 2.8 lb. per ton. By analysis, total aluminum was indicated to be 0.033 per cent. This steel was desired for comparison with the aluminum-killed steel heat 5280 to which was added only 2 lb. of aluminum per ton.

The Inland Steel Co. also supplied a 4 by 4-in. billet from the middle of ingot No. 9 of a rimmed heat 7666 to which was added in the ladle sufficient 60 per cent ferromolybdenum to give a molybdenum content of about 0.58 per cent. In this low-carbon range very little carbon segregation was obtained in the ingot, and although as shown in Fig. 1, the billet section shows a definite rim and core, the carbon contents were 0.06 per cent at both the rim and core locations and the molybdenum contents 0.57 and 0.58 per cent.

A sample of British steel E[3] was obtained for study of the effect of heat treatment on its creep resistance in an effort to explain its reported lack of creep resistance and poor response to a coarsening treatment. Upon request, full details of the melting practice of this steel have been made available by Jenkins. The steel was made in an open-hearth furnace from 57 per cent scrap and 43 per cent pig iron. The charge weighed 36½ tons and was deoxidized with 4 lb. per ton of ferrosilicon and 24 lb. per ton of ferromanganese. The charge was considered to be dead melted. The slag composition was normal. The composition of the metal both before preliminary additions to the bath and at the time of casting was as follows:

	"Pre-add" Metal	Final Metal, Before Fouring
Carbon, per cent	0.12	0.16
Silicon, per cent	0.070	0.110
Sulfur, per cent	0.038	0.037
Phosphorus, per cent	0.043	0.044
Manganese, per cent	0.06	0.08

NOTE: The metal compositions shown are presumed to be before ladle additions. The final manganese content of the heat was 0.40 per cent and has been checked by analysis of a sample supplied by Jenkins.

There were no abnormal happenings during manufacture, and the metal was not held for any unusual period in melting or annealing.

There appears no reason for the poorer creep resistance of this steel other than its low silicon content. Certainly nothing in its melting history provides any explanation.

There have been noted exceptions to the general observations that coarse-grain carbon steel is better than fine-grain steel at the temperature levels of normal use. One is in fine-grain C-V steel, which has good creep resistance in spite of its fine grain. Another is weld metal which has been reported to have good creep resistance in an extremely fine-grain condition.

Through the courtesy of H. J. Kerr and the Babcock & Wilcox Co., samples of deposited weld metal were supplied for test. One sample tested was weld metal deposited from a plain carbon steel rod and three other samples were weld metal deposited from carbon-molybdenum steel rod. The following data were supplied on the preparation of the weld metal samples.

	Electrode Type	A.S.T.M.-A.W.S. Standard Electrode Classification No.	Method of Weld
Weld metal A	Babcock & Wilcox Standard 1467 coating	E 6030	Automatic
Weld metal C	Carbon-molybdenum organic coating	E 7010	Manual
Weld metal D	Carbon-molybdenum organic coating	E 7030 + some organic material	Automatic
Weld metal F	Babcock & Wilcox carbon-molybdenum 1467 coating	E 7030	Automatic

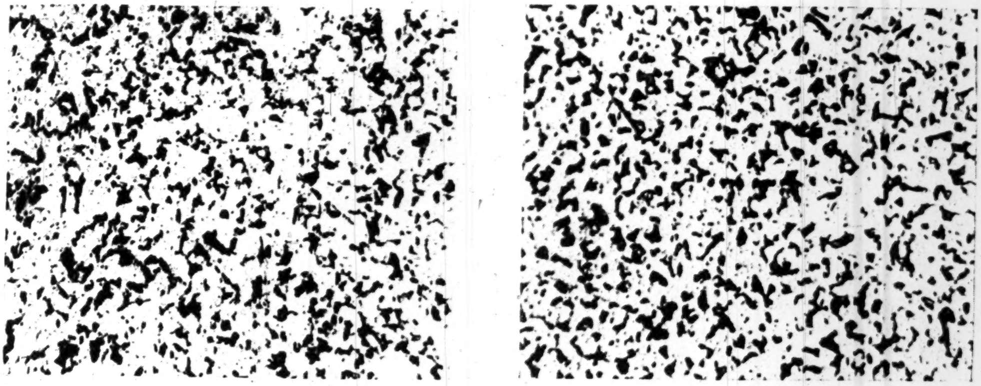
These welds were laid down in a V scarf between plates of the same com-

TABLE II.—CREEP TEST DATA FOR TESTS AT 850 AND 950 F. ON LOW CARBON AND CARBON-MOLYBDENUM STEELS AND WELD METAL.

Steel Designation and Specimen Number.		Carbon, per cent	Deoxidation Practice	Location of Test Material	Load, psi.	Test Temperature, deg. Fahr.	Average Initial Deformation, per cent	Rate of Deformation at 500 hr., per cent per hour	Average Total Deformation at 500 hr., per cent	Heat Treatment A.C. = Air Cooled W.Q. = Water Quenched	Austenite Grain Size, A.S.T.M. Number	Ferrite Grain Size
5247	5247-19	0.14	Silicon-killed	1 in. rounds	15 000	850	0.112	0.000129	0.380	5 min. at 1575 F., A.C.	5 to 7, some 4	Fine
5247	5247-6	0.14	Silicon-killed	1 in. rounds	15 000	850	0.130	0.000045	0.223	1½ hr. at 1800 F., A.C.	2 to 4	Fine
5247	5247-16	0.14	Silicon-killed	1 in. rounds	15 000	850	0.212	0.000094	0.501	1½ hr. at 1800 F., then[n]	2 to 4	Coarse
5247	5247-25	0.14	Silicon-killed	1 in. rounds	15 000	850	0.124	0.00009	0.324	1½ hr. at 1800 F., A.C. 5 min. at 1575 F., A.C.	5 to 7, some 4	Fine
5280	5280-9	0.17	Silicon-aluminum killed	1 in. rounds	15 000	850	0.161	0.015[f]	2.767[f]	1 hr. at 1730 F., A.C.	7 to 8	Fine
5280	5280-1	0.17	Silicon-aluminum killed	1 in. rounds	15 000	850	0.092	0.00006	0.165	1 hr. at 2000 F., A.C.	80% 2 to 4 Some 1 and 5	Fine
5280	5280-6	0.17	Silicon-aluminum killed	1 in. rounds	15 000	850	0.320	0.016[g]	2.935[g]	1 hr. at 2000 F., then[n]	80% 2 to 4 Some 1 and 5	Coarse
5280	5280-21	0.17	Silicon-aluminum killed	1 in. rounds	15 000	850	0.162	0.0015	0.988	1 hr. at 2000 F., then[o]		
5280	5280-17	0.17	Silicon-aluminum killed	1 in. rounds	15 000	850	0.130	0.0047	1.745	1 hr. at 2000 F., A.C., 5 min. at 1730 F., A.C.	7 to 8	Fine
35561	CS-5	0.08	Aluminum-killed, nonaging	Edge-4 in. billet	15 000	850	0.204	0.00726	6.30	2 hr. at 1875 F., A.C.	5 to 7, some 8	Fine
35561	CC-1	0.08	Aluminum-killed, nonaging	Center-4 in. billet	15 000	850	0.143	0.00102	1.638	2 hr. at 2225 F., A.C.	2 to 4, some 1	Fine
35561	CC-2-1	0.08	Aluminum-killed, nonaging	Center-4 in. billet	15 000	850	0.072	0.00004	0.198	2 hr. at 2225 F., W.Q. 1 hr. at 950 F., A.C.	2 to 4, some 1	Fine
7666	BC-1	0.06[b]	Rimmed	Core	15 000	850	0.095	0.000015	0.145	2 hr. at 1725 F., A.C.	5 to 7	Fine
7666	BC-1	0.06[b]	Rimmed	Core	32 000	850	1.887	0.00031[h]	2.475	2 hr. at 1725 F., A.C.	5 to 7	Fine
7666	BC-2-1	0.06[b]	Rimmed	Core	15 000	850	0.104	0.00001	0.120	1½ hr. at 2025 F., A.C.	2 to 4, some 1	Fine
7666	BC-2-1	0.06[b]	Rimmed	Core	32 000	850	1.114	0.00024[i]	1.455	1½ hr. at 2025 F., A.C.	2 to 4, some 1	Fine
7666	BS-2-5	0.06[b]	Rimmed	Skin	15 000	850	0.133	0.000015	0.146	1 hr. at 1975 F., A.C.	2 to 4, some 1	Fine
7666	BS-2-5	0.06[b]	Rimmed	Skin	32 000	850	2.195	0.00036[j]	3.032	1 hr. at 1975 F., A.C.	2 to 4, some 1	Fine
GBE	[a]	0.19	Silicon-killed		17 900	842	0.180	0.00108	1.120	1740 F., A.C.	Fine	Fine
GBE	GBE-1	0.19	Silicon-killed		15 000	850	0.080	0.00015	0.481	1½ hr. at 2000 F., A.C.	2 to 4, some 1	Fine
GBE	[a]	0.19	Silicon-killed		17 900	842	0.300	0.00094	1.300	6 hr. at 2010 F., Slow cooled	Coarse	Coarse
Weld metal A		0.12	...	In weld	15 000	850	0.078	0.00003[k]	0.122	Stress relieved at 1180 F.	Very fine	Very fine
Weld metal C(C-Mo)		0.12[c]	...	In weld	32 000	850	0.162	0.00005[k]	0.268	Stress relieved at 1200 F.	Very fine	Very fine
Weld metal D(C-Mo)		0.14[d]	...	In weld	15 000	950	0.072	0.00004[l]	0.150	Stress relieved at 1200 F.	Very fine	Very fine
Weld metal F(C-Mo)		0.13[e]	...	In weld	32 000	850	0.153	0.00002[k]	0.220	Stress relieved at 1200 F.	Very fine	Very fine
Weld metal F(C-Mo)		0.13[e]	...	In weld	15 000	950	0.070	0.00004[m]	0.128	Stress relieved at 1200 F.	Very fine	Very fine

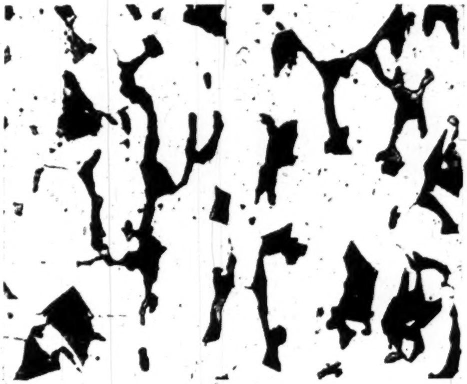
[a] Creep test data taken from work of Jenkins, footnote reference 3. [b] 0.58 per cent moybdenum. [c] 0.48 per cent molybdenum. [d] 0.59 per cent molybdenum. [e] 0.46 per cent molybdenum. [f] At 122 hr. [g] At 102 hr., test discontinued. [h] Final rate at 964 hr. 0.00021 per cent per hour. [i] Final rate at 743 hr. 0.00021 per cent per hour. [j] Final rate at 743 hr., 0.00036 per cent per hour. [k] At 600 hr. [l] At 1000 hr. the rate was 0.00003 per cent per hour and deformation 0.168 per cent. [m] At 1000 hr. the rate was 0.000035 per cent per hour and the deformation 0.145 per cent. [n] Furnace cooled to 1575 F., then cooled 40 F. per hour to 1250 F., then furnace cooled. [o] Furnace cooled to 1585 F., then cooled at 280 F. per hour to 1250 F., then air cooled.

position, but the welds were so wide that it is considered very little of the plate material mixed in with the weld metal. Before testing, the weld material was X-rayed and magnafluxed and appeared to be suitable for testing.



Silicon-killed steel.
Heated 1½ hr. at 1800 F., air cooled.
Heated 5 min. at 1575 F., air cooled.
Austenite grain size Nos. 5 to 7, some No. 4.

Silicon-aluminum-killed steel.
Heated 1 hr. at 2000 F., air cooled.
Heated 5 min. at 1730 F., air cooled.
Austenite grain size Nos. 7 to 8.



Silicon-aluminum-killed steel.
Heated 1 hr. at 2000 F., slow cooled to 1585 F., then cooled 280 F. per hr. to 1200 F., then air cooled.
Austenite grain size Nos. 2 to 4, some Nos. 1 and 5.

Fig. 2.—Structures of Silicon-Killed and Silicon-Aluminum-Killed Steels as Tested in Creep. Etched in 2 per cent Nital (× 100).

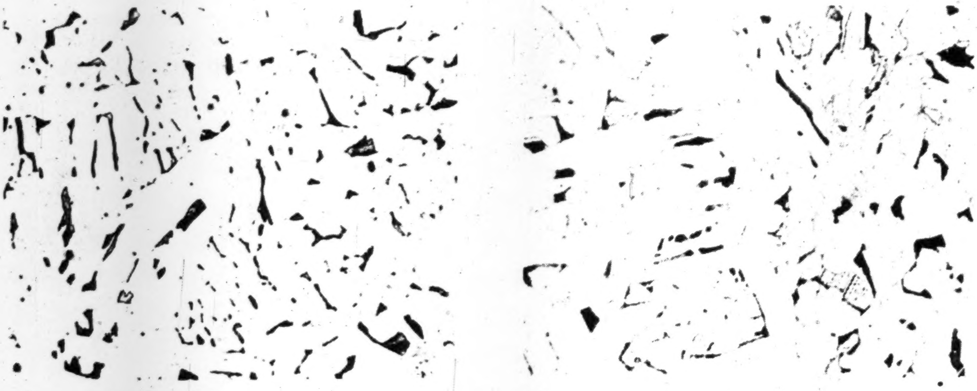
CREEP TEST EQUIPMENT AND PROCEDURE

Throughout the series of creep tests herein reported, the requirements of the A.S.T.M. Recommended Practice for Conducting Long-Time High-Temperature Tension Tests of Metallic Materials (E 22 – 41)[4] have been met or exceeded.

As in the previous work reported, 500-hr. creep tests were used to show extreme differences in creep propensities, but the use of such a short period herein is not to be construed as an endorsement of shortening the period for regular creep tests used for determination of design loads.

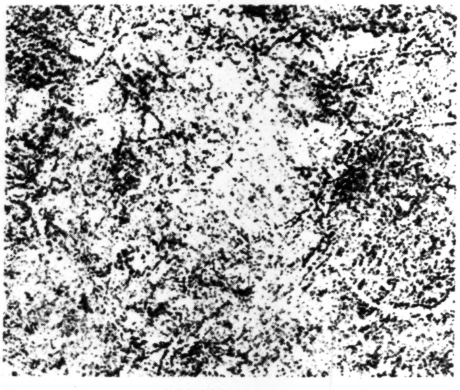
---

[4] 1942 Book of A.S.T.M. Standards, Part I, p. 930.



Heated 2 hr. at 1875 F., air cooled.
Austenite grain size Nos. 5 to 7, some No. 8.

Heated 2 hr. at 2225 F., air cooled.
Austenite grain size Nos. 2 to 4, some No. 1.



Heated 2 hr. at 2225 F., water quenched; tempered 1 hr. at 950 F., air cooled.
Austenite grain size Nos. 2 to 4, some No. 1.

FIG. 3.—Structures of Aluminum-Killed Nonaging Steel as Tested in Creep. Etched in 2 per cent Nital (× 100).

GRAIN COARSENING EXPERIMENTS, HEAT TREATMENTS USED, AND STRUCTURES PRODUCED IN THE VARIOUS STEELS FOR CREEP TEST

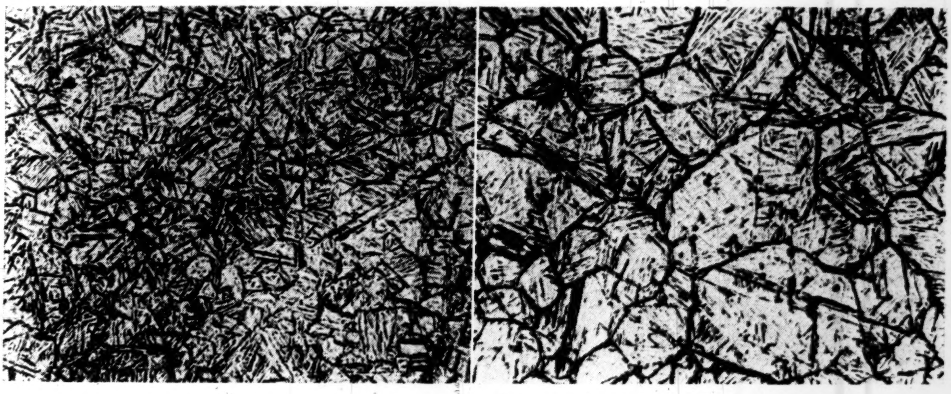
In the previous reports, pure irons and steels up to 0.58 per cent carbon were heat treated to produce fine austenite grain size generally ranging from Nos. 5 to 8 and coarse austenite grain size from Nos. 2 to 4 as measured by A.S.T.M. Tentative Classification of Austenite Grain Size in Steels (E 19 – 39 T.)[5] This spread in grain size was accompanied by significant differences in creep resistance of the various steels.

In the work on the steels herein reported, grain sizes as fine as Nos. 6 to 8 were not always obtainable, so a fine austenite grain size of Nos. 5 to 7 and a coarse austenite grain size of Nos. 2 to 4 were produced in all steels as nearly as possible. These austenite grain sizes are the result of the combination of the times and temperatures used in the various heat treatments which are shown in Table II. Austenite grain sizes were measured by the heat etching method described by Day and Austin.[6]

---

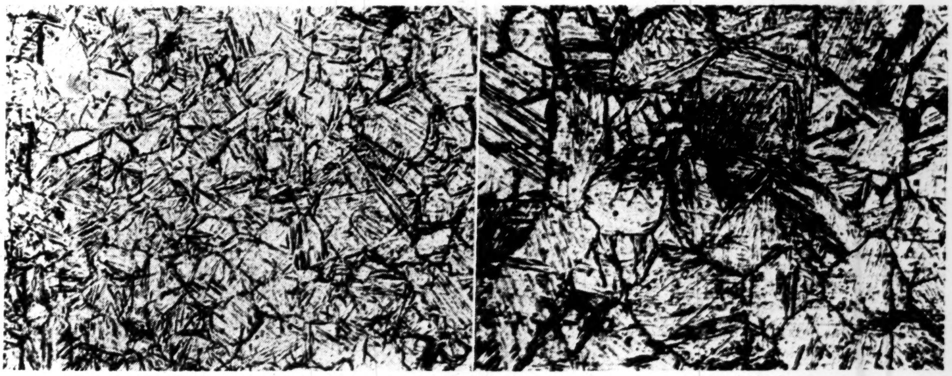
[5] 1942 Book of A.S.T.M. Standards, Part I, p. 1534.

The grain coarsening characteristics of the silicon-killed and the silicon-aluminum-killed steels had been previously determined,[2] and the same heat treatments were used to produce the desired fine and coarse austenite grain sizes.



Core
Heated 2 hr. at 1725 F., air cooled.
Grain size Nos. 5 to 7.

Core
Heated 1½ hr. at 2025 F., air cooled.
Grain size Nos. 2 to 4, some Nos. 1 and 5.



Skin
Heated 2 hr. at 1725 F., air cooled.
Grain size Nos. 5 to 7.

Skin
Heated 1 hr. at 1975 F., air cooled.
Grain size Nos. 2 to 4, some No. 1.

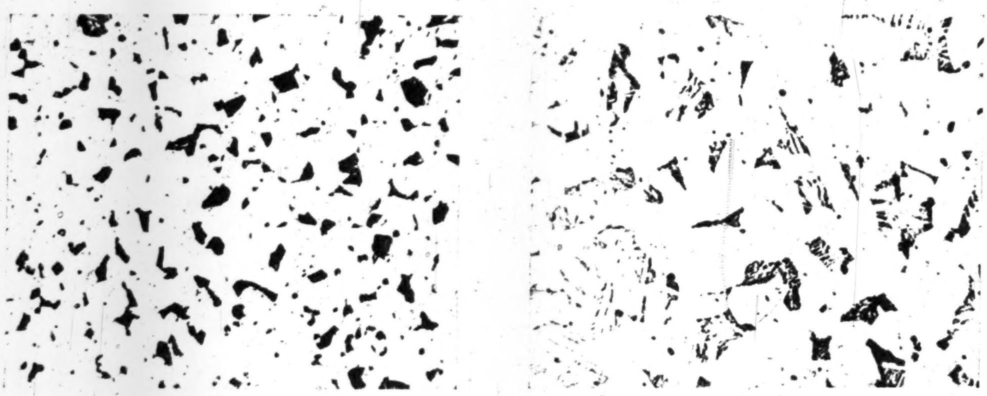
FIG. 4.—Austenite Grain Sizes of Carbon-Molybdenum Rimmed Steel. 0.06 per cent carbon 0.58 per cent molybdenum (× 100).

The joint committee requested that a determination be made of the effect on the creep resistance of refining of the austenite grain subsequent to a coarsening treatment which had improved the creep resistance materially as compared with the steel in the fine-grain condition.

---

[6] M. J. Day and J. B. Austin, "Heat Etching as a Means of Revealing Austenite Grain Size," *Transactions*, Am. Soc. Metals, Vol. 28, pp. 354–68 (1940).

The silicon-aluminum-killed steel (2 lb. aluminum per ton) was chosen for this test and for purposes of comparison the silicon-killed steel 5247 was also tested. Figure 2 shows the structures of these two steels after a preliminary coarsening treatment followed by a 5-min. heating at a temperature producing a fine austenite grain size, and air-cooling. The structure of the two steels is quite similar.



Core

Heated 2 hr. at 1725 F., air cooled.
Austenite grain size Nos. 5 to 7.

Core

Heated $1\frac{1}{2}$ hr. at 2025 F., air cooled.
Austenite grain size Nos. 2 to 4, some Nos. 1 and 5.

Skin

Heated 1 hr. at 1975 F., air cooled.
Austenite grain size Nos. 2 to 4, some No. 1.

FIG. 5.—Structures of Carbon-Molybdenum Rimmed Steel. 0.06 per cent carbon, 0.58 per cent molybdenum as tested in creep. Etched in 2 per cent Nital (× 100).

The previous report[2] showed slow cooling from the coarsening temperature of the silicon-aluminum killed steel produced poor creep resistance. Figure 2 shows the structure of this steel when cooled at the faster cooling rate of 280 F. per hour through the critical range. The structure produced by this somewhat faster cooling rate was very similar to that produced by a cooling rate of 40 F. per hour in material previously tested.

The aluminum-killed nonaging steel, as a consequence of its higher aluminum addition, required heating at a higher temperature to produce the desired grain sizes as compared with the other steels. For an austenite grain size of Nos. 5 to 7, some No. 8, heating for 2 hr. at 1875 F. was required and for a grain size of Nos. 2 to 4, some No. 1, heating at 2225 F. for 2 hr. was required. The structures produced by both heat treatments were of the Widmanstätten type (Fig. 3). The structure of this steel as water quenched from the coarsening temperature and tempered at 950 F. is also shown in Fig. 3, since the creep tests on the normalized fine- and coarse-grained material indicated the need for such a test.

The heat treatments required to produce the desired grain sizes in the rimmed carbon-molybdenum steel are shown in Table II. As an example of the method of determining the austenite grain sizes, Fig. 4 shows heat-etched specimens of both fine- and coarse-grain core and skin material of this carbon-molybdenum rimmed steel. As would be expected, a slightly higher temperature was required to coarsen the core than the skin material. Figure 5 shows the structures of this steel as tested in creep. The fine-grained skin material was not tested in creep. The other three materials show a Widmanstätten type of structure differing only in the different austenite grain sizes from which they were derived. It is of interest to note these structures since all three show practically the same creep resistance.

No determination of the grain size produced by the heat treatments used on steel GBE by Jenkins, et al.,[3] were made, but it is likely that heating at 1740 F. followed by air-cooling produced an austenite grain size of about Nos. 5 to 6 and a fine ferrite grain size. Heating at 2010 F. for 6 hr. followed by slow cooling would produce a coarse austenite and ferrite grain size. In the experiments herein conducted, heating at 2000 F. for $1\frac{1}{2}$ hr. followed by air-cooling produced an austenite grain size of Nos. 2 to 4, some No. 1, and a fine ferrite grain size.

Figure 6 shows the structure of this steel E in the condition as tested in creep after air-cooling from 2000 F. The structure is typical of air-cooled coarsened steels and is of the Widmanstätten type.

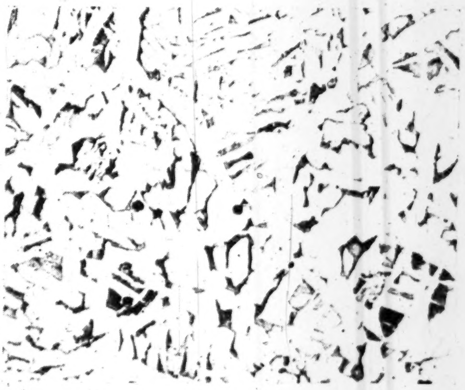


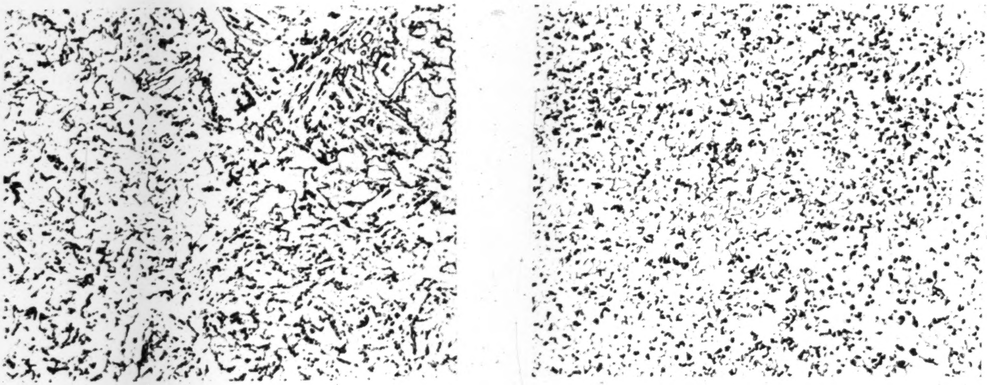
FIG. 6.—Structure of British Steel E, 0.19 per cent carbon, 0.40 per cent manganese 0.08 silicon as tested in creep. Etched in 2 per cent Nital (× 100). Heated $1\frac{1}{2}$ hr. at 2000 F., air cooled.

Figure 7 shows the structures of the weld metals A, C, and F as tested in creep. All are very fine-grain. The structures varied a little from pass to pass. Notice in weld metal A patches with structure of the Widmanstätten type.

Room temperature tensile and impact properties have been determined for most of the steels as given the various heat treatments and these will be discussed later in the report.

CREEP TESTS

Most of the creep tests were made at 850 F. to permit comparisons with the previous tests. Several of the carbon-molybdenum weld metal test specimens were also tested at 950 F. The creep test data obtained are shown in Table II.

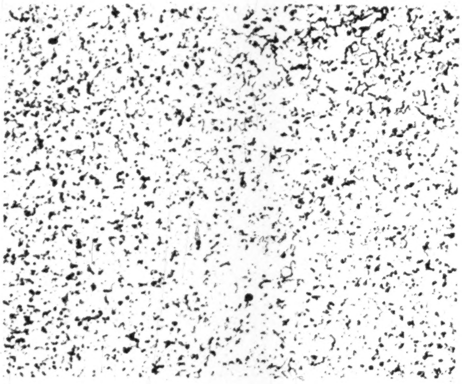


Weld Metal A

0.12 per cent carbon, 0.66 per cent manganese, 0.24 per cent silicon. Stress-relieved at 1180 F.

Weld Metal C

0.12 per cent carbon, 0.52 per cent manganese, 0.23 per cent silicon, 0.48 per cent molybdenum. Stress-relieved at 1200 F.



Weld Metal F

0.13 per cent carbon, 0.66 per cent manganese, 0.18 per cent silicon, 0.46 per cent molybdenum. Stress-relieved at 1200 F.

FIG. 7.—Structure of Weld Metals as Tested in Creep. Etched in 2 per cent Nital (× 100).

Figure 8 shows the time-deformation curves at 850 F. for the silicon-killed steel. As was previously shown, coarsening produced only a little improvement in creep resistance, which as fine-grain was already quite good. Slow cooling from the coarsening temperature produced no significant change in creep resistance. Therefore, it was not unexpected that specimen 5247–25 when tested as first coarsened and then heated for 5 min. at 1575 F. and air cooled showed a creep rate intermediate between the rates shown by the steel as heat treated to produce fine and coarse austenite grain size.

Figure 8 also shows the time-deformation curves at 850 F. for the silicon-

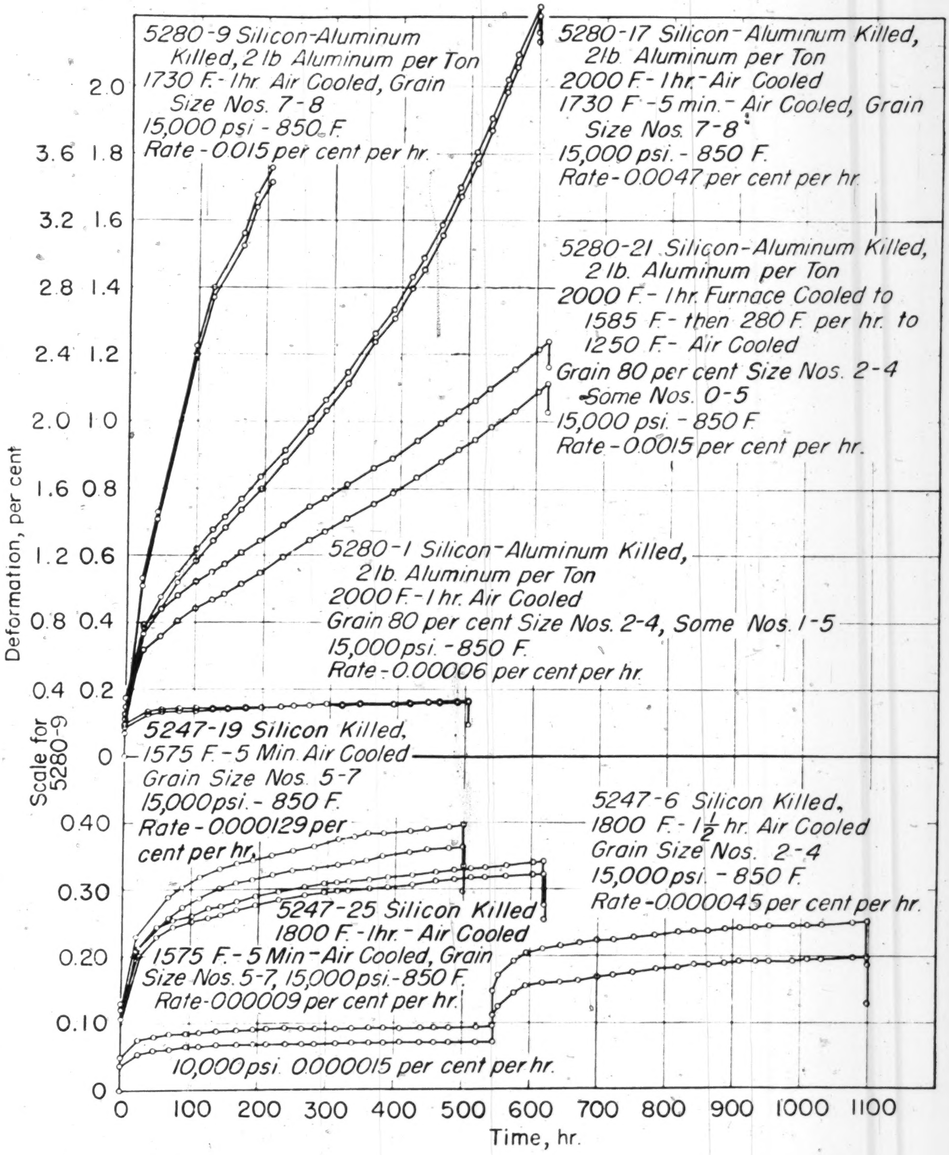


FIG. 8.—Time-Deformation Curves for Silicon-Killed and Silicon-Aluminum Killed Steels.

aluminum-killed steels. It was previously shown that this steel when heat treated to produce a fine austenite grain size showed very poor creep resistance. Coarsening followed by air cooling produced good creep resistance similar to that for a silicon-killed steel similarly coarsened and air cooled. Slow cooling of this silicon-aluminum-killed steel from the coarsening temperature and through the critical range (40 F. per hour from 1585 F. to 1250 F.) had produced the same rapid creep rate as for fine-grain material. Figure 8 also shows the time-deformation curve for specimen 5280–21 which was coarsened and then more rapidly cooled at 280 F. per hour through the temperature range 1585 to 1250 F. This specimen showed a creep rate of 0.0015 per cent per hour, a lower rate of creep than for the material cooled at the slower rate of 40 F. per hour, but not as low a rate as for specimen 5280–1 air cooled from the coarsening temperature.

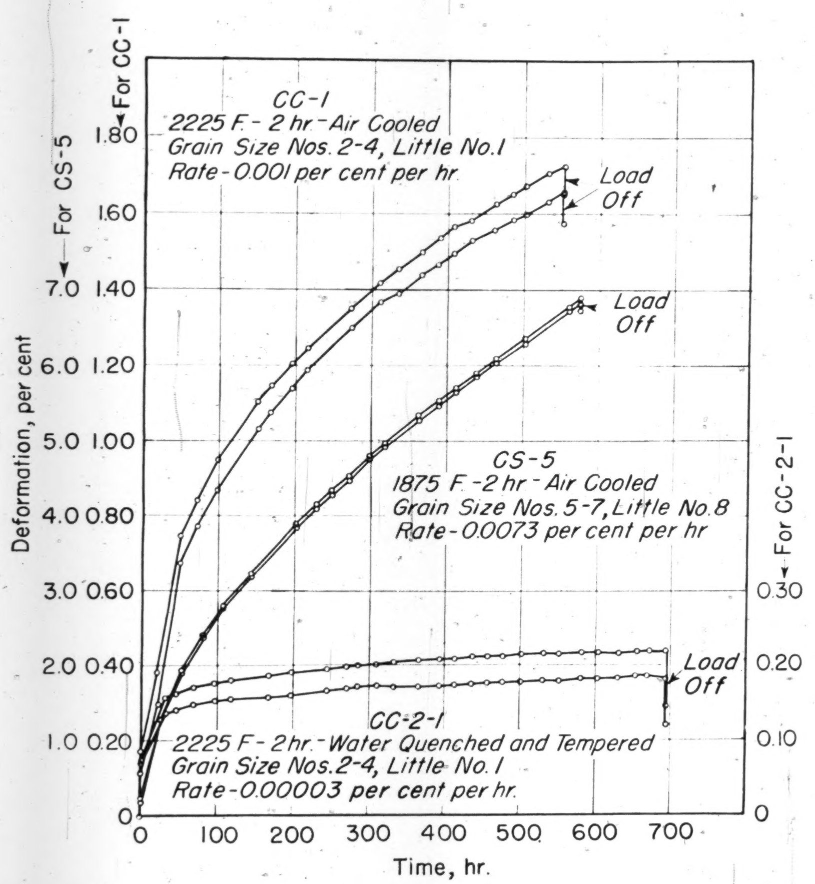


FIG. 9.—Time-Deformation Curves for Fine-Grain Nonaging Steel. 0.08 per cent carbon, 2.8 lb. aluminum per ton.

When specimen 5280–17 was tested as coarsened and then reheated to 1730 F. for 5 min. and air cooled, the creep rate was 0.0047 per cent per hour, which is to be compared with the rate for the fine-grain steel (0.015 per cent per hour). It is indicated for this silicon-aluminum-killed steel that the good creep properties imparted by coarsening and subsequent rapid cooling are practically eliminated by a short-time recrystallization heat treatment which again produced a fine austenite grain size.

Figure 9 shows the time-deformation curves at 850 F. for the aluminum-killed nonaging steel. When heat treated to produce a fine austenite grain size, (CS-5) a very rapid rate of creep was shown. Surprisingly, while coarsening of the austenite grain size followed by air cooling did produce a slight improvement in creep resistance (0.0073 to 0.0010 per cent per hour), the creep rate as coarsened and air cooled was still far in excess of the creep rates produced in the silicon-killed and silicon-aluminum-killed steels by similar grain-coarsening heat treatments. It seemed plausible because of the high aluminum addition resulting in appreciable amounts of both metallic aluminum and Al_2O_3, that air cooling was not fast enough to produce the particle size and dispersion of the nonmetallics postulated necessary to produce good creep resistance. A critical cooling rate below which significant improvement in creep resistance could not be effected has been considered as a possibility. To check on this point a sample of this aluminum-killed nonaging steel was water quenched from the coarsening temperature and then tempered at 950 F. prior to creep testing at 850 F. The creep resistance of the steel as coarsened, quenched and tempered was as good as that obtained with any of the other silicon, aluminum, or silicon-aluminum-killed steels as air cooled. Owing to the high aluminum addition to this steel, a very high temperature (2225 F.) was required to produce coarsening; therefore, a strong tendency for precipitation of grain-growth inhibiting material should exist and air cooling would not be expected to be rapid enough to produce the fine dispersed particles thought responsible for good creep resistance. Here is a most interesting and unusual example of a steel as quenched and drawn showing better creep resistance than when normalized.

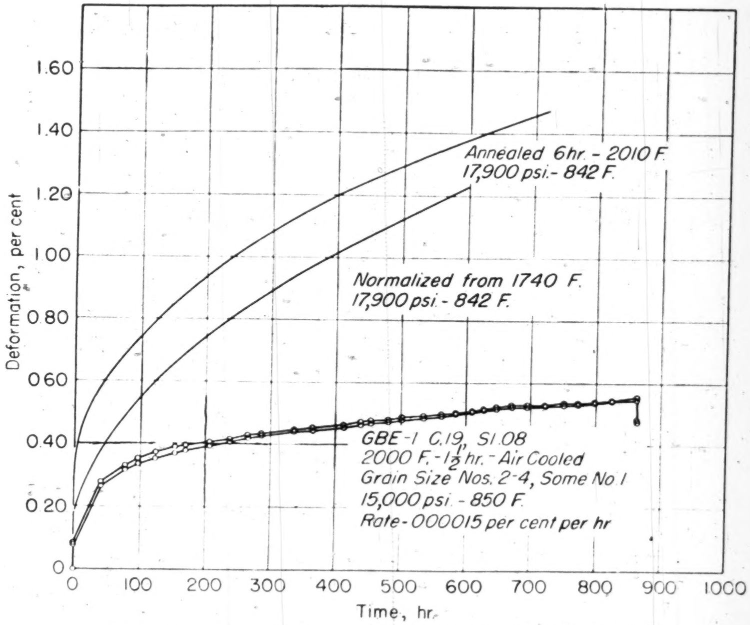


Fig. 10.—Time-Deformation Curves for British Steel E.

In Fig. 10 are shown the time-deformation curves for the British steel E tested by Jenkins, *et al.*[3] This steel was out-

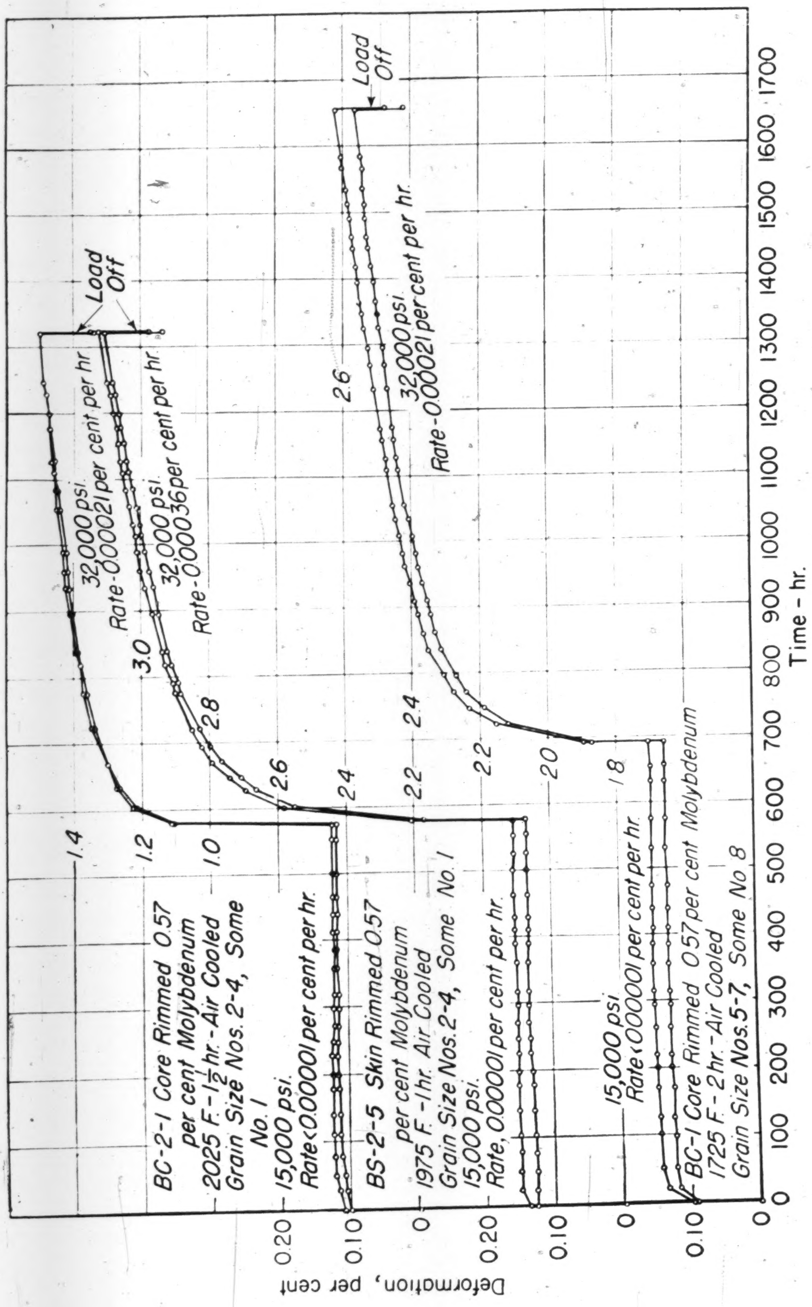


FIG. 11.—Time-Deformation Curves for Carbon-Molybdenum-Rimmed Steel.

standing in a series of steels tested by them in that it showed poor creep resistance as compared with the others, for no apparent reason. As normalized from 1740 F., and tested at 842 F. and at 17,900 psi., the creep rate at 480 hr. was 0.00108 per cent per hour. This is not so rapid a rate as was shown by the aluminum-killed steel and the silicon-aluminum-killed steels in Fig. 8. However, the creep rate for this steel E was considerably in excess of what would be expected from a silicon-killed steel. Jenkins had also tested the steel as slow-cooled from 2010 F. and as shown in Fig. 10, practically no change in creep resistance occurred as a result of this treatment. With data available for other types of steels on the effect of cooling rate on creep resistance, it was decided to air cool a bar of this steel E from the coarsening temperature. A creep test was run at 850 F. and 15,000 psi., and a rate of deformation of 0.00015 per cent per hour was shown at 500 hr. Judging from the test by Jenkins on the slow-cooled material at 17,900 psi., a test at 15,000 psi. would show about 0.0004 per cent per hour. Hence, the air cooling which produced a creep rate of 0.00015 per cent per hour was an improvement, but it is definitely indicated that this steel does not show quite so low a creep rate as would be expected from either a fine-grain or coarse-grain silicon-killed steel.

Figure 11 shows the time-deformation curves for the rimmed carbon-molybdenum steel. This steel was included in the work for this project for the purpose of determining whether molybdenum would exhibit its usual capacity for improving creep resistance even when added to a rimmed steel notorious for its poor creep properties. The creep tests were first run at 850 F. and 15,000 psi. and later the stress was increased to 32,000 psi. so as to permit a direct comparison with some other data on killed carbon-molybdenum steels.[7] At the lower stress the creep rates were so low that no difference between the core and skin materials or the various austenite grain sizes could be determined. At the higher stress, as with previous tests on rimmed steels, the core material showed better creep resistance than the skin material as air cooled from their respective coarsening temperatures. The differences in creep rate were not large (core 0.00024 and skin 0.00036 per cent per hour), but the differences in total deformation at the termination of the test were very large indeed. For instance, at 500 hr. the skin material of this carbon-molybdenum rimmed steel as coarsened showed a rate of 0.00036 per cent per hour and a total deformation of 3.03 per cent, while the core material showed a rate of 0.00024 per cent per hour and a total deformation of about 1.45 per cent. In the fine-grain condition only the core material was tested and while the total deformation at 500 hr. was greater than when tested as coarsened (2.475 per cent as compared with 1.455 per cent), the creep rates were not greatly different (0.00031 fine-grain and 0.00024 per cent per hour coarse-grain). Both showed a further reduction in creep rate beyond 500 hr., and at 964 hr. for the core fine-grain and 743 hr. for core coarse-grain, the rate was 0.00021 per cent per hour.

These results are most interesting when compared with data presented by Miller[7] on killed carbon-molybdenum steel. This steel contained 0.11 per cent carbon, 0.14 silicon, and had an aluminum addition of 1.5 lb. per ton. At 850 F. and 32,000 psi. in the fine-grain condition (heated 5 min. at 1750 F.,

---

[7] R. F. Miller, "Effect of Deoxidation Practice on Creep Strength of Carbon-Molybdenum Steel at 850 and 1000 F.," *Transactions*, Am. Soc. Mech. Engrs. May, 1943, Vol. 65, No. 4, p. 309.

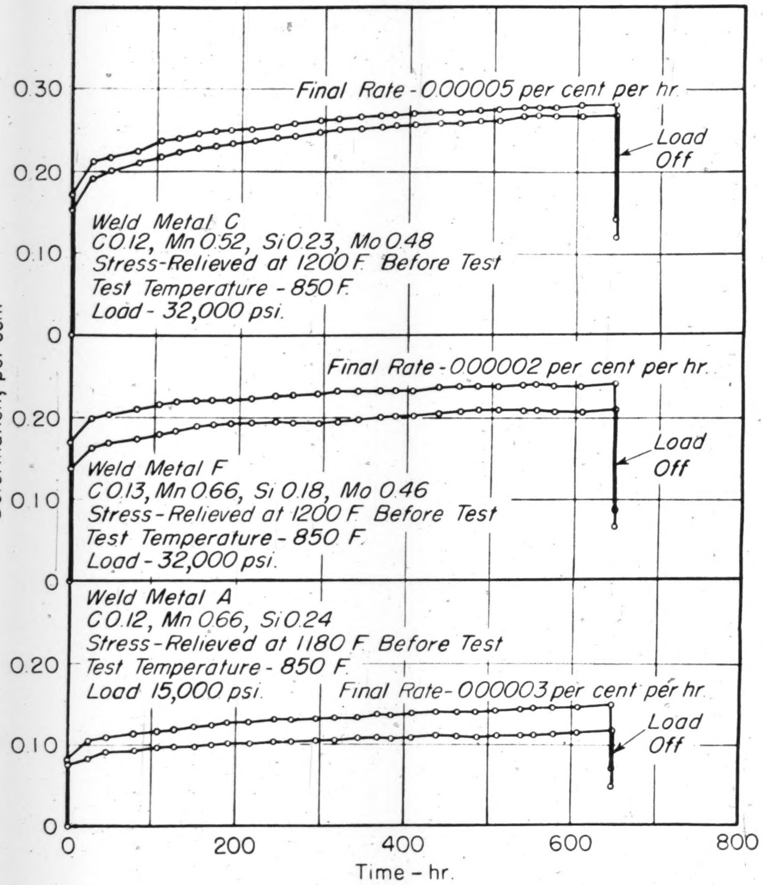


FIG. 12.—Time-Deformation Curves at 850 F. for Carbon and Carbon-Molybdenum Weld Metal.

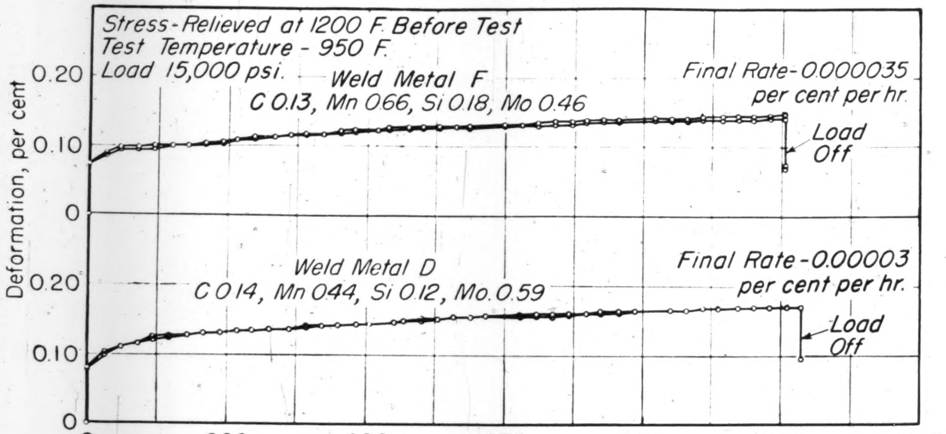


FIG. 13.—Time-Deformation Curves at 950 F. for Carbon-Molybdenum Weld Metal.

air-cooled), the creep rate between 500 and 1000 hr. was 0.00009 per cent per hour (intercept deformation 1.91 per cent), falling to 0.00006 per cent per hour at 2000 hr. In the coarse-grain condition as slow-cooled, the rate between 500 and 1000 hr. was 0.00019 per cent per hour (intercept deformation 3.83 per cent), falling to 0.000075 per cent per hour at 2000 hr. The rimmed steel showed rates roughly 2½ to 4 times those of the killed steel, but the rimmed steel was 0.05 per cent lower in carbon and it is well known that small differences in carbon content in the low ranges have an appreciable effect. Such small differences in creep rate amount to very little in allowable stresses and might be largely eliminated by equal carbon content in the two steels.

Figures 12 and 13 show the time-deformation curves for the weld metal tested in creep at 850 and 950 F. These weld metal specimens were stress-relieved at 1180 or 1200 F. after welding. No additional heat treatments were used prior to creep testing. Weld metal A which was deposited with a plain carbon steel electrode (0.12 per cent carbon, 0.24 silicon) was tested at 850 F. and 15,000 psi. for comparison with the other wrought plain carbon steels. This fine-grain weld metal showed as good creep resistance as the coarsened wrought silicon-killed steel. Weld metals C (0.12 per cent carbon, 0.23 silicon, 0.48 molybdenum) and F (0.13 per cent carbon, 0.18 silicon, 0.46 molybdenum) were tested at 850 F. and 32,000 psi. and showed creep rates of 0.00005 and 0.00002 per cent per hour, respectively. These creep rates are as low or lower than have been obtained under these test conditions on any wrought carbon-molybdenum steel. The same applies to weld metals D and F when tested at 950 F. and 15,000 psi. These low creep rates were obtained in conjunction with total deformations ranging from only 0.10 to 0.30 per cent in tests of 650 to 1000 hr. For details see Table II and Figs. 12 and 13.

DISCUSSION OF RESULTS

SAE 1015 Steels:

The experiments herein described do not suggest a change from the hypothesis previously advanced that at least in plain carbon steels it seems to be the absence or presence of inclusions of various types and compositions whose size, mode, and degree of dispersion determine in significant manner their creep resistance. It has been shown that deoxidation practice and heat treatment are important factors.

Additional data on the effect of heat treatment are presented for the silicon-killed steel 5247 and the silicon-aluminum-killed steel 5280. The silicon-killed steel which has good creep resistance when heat treated to produce either a fine or coarse austenite grain size is understandably not much affected by different rates of cooling. It likewise shows creep resistance intermediate between the rates for the fine- and coarse-grain conditions when it is reheated for only 5 min. above the critical and air cooled subsequent to a previous coarsening treatment.

But with the silicon-aluminum-killed steel which had an addition of 2 lb. per ton of aluminum, it was quite different. In this steel, in which it was shown previously that the high aluminum apparently wipes out the beneficial effects of silicon in the fine-grain condition, heat treatment is a very important factor in the creep resistance.

It was predicted that since the fine-grain steel showed poor creep properties and the coarse-grain air-cooled steel showed good creep properties, varying degrees of creep resistance would be obtained by varying the rate of cooling from the coarsening temperature. Specimen 5280–6 which was slow-cooled (40 F. per hour through the critical range) was no better in creep than the fine-grain material. But specimen 5280–21 which was cooled at 280 F. per hour from 1585 to 1250 F. showed a creep rate more than ten times slower than 5280–6, yet still 25 times faster than for coarsened and air-cooled specimen 5280–1. A more complete survey would be needed to indicate more quantitatively the effect of cooling rate in this silicon-aluminum-killed steel. However, it does appear that the faster the cooling rate the better the creep resistance, and this probably means that there is a finer and better dispersion of the postulated nonmetallic inclusions obtained with the faster cooling rates. Heating at 1730 F. for 5 min., subsequent to a previous coarsening treatment which had produced good creep resistance, almost completely eliminated the good creep resistance so obtained. This heating produced a fine-grain austenite, and it appears the time at this temperature may have been sufficient to allow precipitation and agglomeration of whatever the constituent so that fine-grain material of relatively poor creep resistance was the result. It is likely that a longer time at 1730 F. would have further lowered the creep resistance to the value previously shown by this silicon-aluminum-killed steel when given only a single treatment to produce fine grain.

Further experiments looking into the proposed hypothesis were made in a study of the aluminum-killed nonaging steel. As heat treated to produce a fine austenite grain, the creep resistance was poor as was the case for the other aluminum-killed steel tested (5229). The larger aluminum addition of 2.8 lb. per ton required a higher temperature to produce a steel of comparable grain size. This indicated a large amount of grain-inhibiting material present. This indication was confirmed when it was necessary to heat this steel to 2225 F. to coarsen the austenite grain size to the desired size of A.S.T.M. Nos. 2 to 4, some No. 1. Air cooling from the coarsening temperature did not produce the expected improvement in creep resistance, which indicated that possibly the inclusions were sufficiently insoluble; so a suitable precipitation and dispersion were not obtained during air cooling. A specimen water quenched from the coarsening temperature and then tempered at 950 F. prior to test at 850 F. did show excellent creep resistance. Such behavior was additional verification that depending on the deoxidation practice, various cooling rates from the coarsening temperature produce varying degrees of creep resistance in plain carbon steels.

The only moderate improvement in creep resistance obtained when the British steel E was normalized from the coarsening temperature, along with its creep resistance in the fine-grain condition not being up to expectations for a silicon-killed steel, suggest that the silicon content of 0.09 per cent is not sufficient to provide the silicon-containing inclusions postulated necessary for the best creep resistance in the fine-grain condition. This seems the only explanation in view of the fact that no aluminum was added to this heat. The results obtained on this steel with 0.09 per cent silicon suggest a more careful study of steels with silicon contents ranging from the minimum required to produce a killed steel up through the higher silicon-containing grades with silicon of about 0.30 per cent.

The tests on the rimmed steel to which molybdenum was added indicate that as in the case of killed steels, molybdenum improves the creep resistance.

As in the case of plain carbon rimmed steel, the core material showed slightly better creep resistance than the skin material, and coarsening of the core material produced some slight improvement in creep resistance. This carbon-molybdenum rimmed steel is not quite so creep resistant as an aluminum-killed carbon-molybdenum steel tested by Miller,[7] but the carbon content of the rimmed carbon-molybdenum steel was 0.05 per cent lower which is probably a significant difference with regard to creep resistance. The data at hand indicate that the addition of molybdenum largely offsets differences in creep resistance owing to differences in deoxidation practice, but not entirely so, as was evidenced by the work of Miller which, while some differences were shown, did not show the huge differences between carbon-molybdenum steels with low and high aluminum additions that were found with plain carbon steels. The true relationship of rimmed carbon-molybdenum steel to killed carbon-molybdenum steel will only be known when a rimmed carbon-molybdenum steel of about 0.15 per cent carbon has been obtained and tested so that direct comparisons can be made.

If rimmed carbon-molybdenum steel should prove equal in creep resistance to killed carbon-molybdenum steel, the practical significance of the use of rimmed rather than killed carbon-molybdenum steel in larger ingot yields, formability, working, and welding should be obvious. Even if rimmed carbon-molybdenum steel was not usable for manufacture of seamless tubing, it should certainly be of use for the manufacture of plate. Another aspect that should be considered is the relative tendency of rimmed carbon-molybdenum steel to graphitize as compared with killed carbon-molybdenum steel. If silicon-killed carbon-molybdenum steel should show a lesser tendency to graphitize as compared with a silicon-aluminum-killed carbon-molybdenum steel, a rimmed steel might show still less tendency as a result of the lack of silicon-containing inclusions thought to be present in silicon-killed steels. It would appear desirable to include rimmed carbon-molybdenum steel specimens in any graphitization experiments on carbon-molybdenum steel.

As in the case of the fine-grain carbon-vanadium steel previously reported,[1] the tests at 850 F. on the plain-carbon and at 850 and 950 F. on the carbon-molybdenum weld metal are further evidence that fine-grain materials can show excellent creep resistance. Miller[7] showed fine-grain carbon-molybdenum steel superior at 850 F., but coarse-grain carbon-molybdenum steel better at 1000 F. The very rapid cooling incident to the weld deposition not only produced a fine grain size but probably retained in solution and then precipitated in an optimum fine dispersion the inclusions or carbides that produce good creep resistance in plain carbon and carbon-molybdenum steels when best heat treated. It is certainly indicated that weld metal so deposited is equal in creep resistance to or better than wrought steel of the same composition, heat treated to optimum creep resistance.

ROOM TEMPERATURE PHYSICAL PROPERTIES OF FINE-GRAIN AND COARSE-GRAIN STEELS

Table III shows the available room temperature physical properties of the various steels tested.

In the previous report,[2] it was shown that coarsening of the silicon-killed and silicon-aluminum-killed steels which improved their creep resistance produced no significant change in room temperature tensile strength or ductility but did produce some lowering of the yield strength and for the silicon-aluminum-killed steel some lowering of the impact resistance. Slow cooling from the coarsening temperature as compared with air cooling produced a still lower yield strength for the silicon-aluminum-killed steel and lower impact resistance for both steels. An intermediate cooling rate for the silicon-aluminum-killed steel between air cooling and slow cooling, which produced an intermediate creep rate, resulted in an improved yield strength and impact resistance as compared with the slow-cooled material. For both steels, refining of the austenite grain size subsequent to coarsening, largely restored the original tensile and impact properties of the fine grain condition, and their creep rates approached the values shown by material normalized from a temperature producing fine austenite grain size.

TABLE III.—ROOM TEMPERATURE PHYSICAL PROPERTIES OF THE FINE-GRAIN AND COARSE-GRAIN STEELS AND WELD METAL.

Steel Designation and Identification	Carbon, per cent	Heat Treatment A.C. = Air Cooled, W.Q. = Water Quenched	Austenite Grain Size, A.S.T.M. Number	Yield Point, psi.	Tensile Strength, psi.	Elongation in 2 in., per cent	Reduction of Area, per cent	Charpy Impact Resistance, ft-lb.[g]
5247 silicon-killed	0.14	5 min. at 1575 F., A.C.	5 to 7, some 4	41 000	58 415	42.0	69.3	51
	0.14	1½ hr. at 1800 F., A.C.	2 to 4	34 125	58 250	41.3	68.7	51
	0.14	1½ hr. at 1800 F., then[e]	2 to 4	34 190	55 570	30.8	62.6	25
	0.14	1½ hr. at 1800 F., A.C. 5 min. at 1575 F., A.C.	5 to 7, some 4	36 200	57 100	41.5	68.8	48
5280 silicon-aluminum killed	0.17	1 hr. at 1730 F., A.C.	7 to 8	47 400	60 525	42.7	70.6	51
	0.17	1 hr. at 2000 F., A.C.	80% 2 to 4 Some 1 and 5	36 800	60 625	41.0	66.4	41
	0.17	1 hr. at 2000 F., then[e]	80% 2 to 4 Some 1 and 5	27 170	54 850	39.5	61.2	32
	0.17	1 hr. at 2000 F., then[f]	80% 2 to 4 Some 1 and 5	33 370	59 520	40.7	63.6	43
	0.17	1 hr. at 2000 F., A.C. 5 min. at 1730 F., A.C.	6 to 8, trace 3	46 670	60 800	42.0	70.5	51
35561 aluminum-killed, nonaging	0.08	2 hr. at 1875 F., A.C.	5 to 7, little 8	28 900	48 050	46.7	74.7	58
	0.08	2 hr. at 2225 F., A.C.	2 to 4, some 1	27 600	49 600	43.5	69.0	53
	0.08	2 hr. at 2225 F., W.Q.	2 to 4, some 1	...	67 400	22.0	...	...
	0.08	2 hr. at 2225 F., W.Q. 1 hr. at 950 F., A.C.	2 to 4, some 1	36 100	43 850	36.5	85.7	53
7666 carbon-molybdenum rimmed, Core	0.06[a]	2 hr. at 1725 F., A.C.	5 to 7	36 570	53 100	44.5	...	57
Core	0.06[a]	1½ hr. at 2025 F., A.C.	2 to 4, some 1	31 500	55 950	39.2	74.1	59
Skin	0.06[a]	1 hr. at 1975 F., A.C.	2 to 4, some 1	29 370	50 920	43.7	78.3	64
Weld metal A	0.12	Stress-relieved at 1180 F.	fine	49 700	65 000	35.5	64.7	...
Weld metal C (C-Mo)	0.12[b]	Stress-relieved at 1200 F.	fine	55 800	66 500	27.7	65.8	...
Weld metal D (C-Mo)	0.14[c]	Stress-relieved at 1200 F.	fine	59 500	72 370	28.7	62.2	...
Weld metal F (C-Mo)	0.13[d]	Stress-relieved at 1200 F.	fine	63 000	74 870	30.2	62.8	28

[a] 0.58 per cent molybdenum.
[b] 0.48 per cent molybdenum.
[c] 0.59 per cent molybdenum.
[d] 0.46 per cent molybdenum.
[e] Furnace cooled to 1575 F., then cooled at 40 F. per hour to 1250 F., then furnace cooled.
[f] Furnace cooled to 1585 F., then cooled at 280 F. per hour to 1250 F., then air cooled.
[g] Keyhole notch.

For the aluminum-killed nonaging steel, coarsening followed by air cooling, which produced some improvement in creep resistance at 850 F., did not significantly change the tensile properties or impact resistance. Coarsening followed by water quenching and tempering which produced a very low creep rate lowered the tensile strength a little but increased the yield strength.

For the carbon-molybdenum rimmed steel (core), coarsening produced no significant change in room temperature tensile properties or impact resistance. The yield and tensile strengths of the coarsened skin material of the rimmed carbon-molybdenum steel were a little lower than for the core material.

The tensile and yield strengths of the carbon and carbon-molybdenum weld metals were somewhat higher than the wrought carbon and rimmed carbon-molybdenum steel.

These data, as did the data in previous reports, show that the creep resistance of the various steels given the various heat treatments could not be predicted from their room temperature physical properties.

FUTURE WORK AND STEELS AVAILABLE FOR TEST

The previous work has shown that 1 lb. of aluminum per ton did not and 2 lb. per ton did adversely affect the creep resistance of a silicon-killed steel in the fine-grain condition. This suggests a relationship between silicon and aluminum additions for production of good creep-resistant carbon steels. Tests are needed on steels with silicon contents less than and greater than 0.15 per cent in small-step increments. There exists the possibility that with some specific silicon content, a fine-grain steel with good creep resistance might be obtained. That is, with an aluminum addition sufficient to give fine grain, a silicon content somewhat higher than the 0.15 per cent normally used might give better creep resistance.

The work on the British steel E with 0.09 per cent silicon suggested the need for a study of steels with silicon contents just sufficient to kill the steel and upward in small steps.

The following steels have been obtained for these proposed tests. The American Steel and Wire Co. has supplied a semikilled steel of the following composition: 0.16 per cent carbon, 0.54 manganese, 0.012 phosphorus, 0.036 sulfur, 0.07 silicon, and 0.17 copper. No aluminum was added to this heat and it should provide a good comparison with the British steel E which contained 0.09 per cent silicon.

To complete the series with low silicon, the Bethlehem Steel Co. has supplied bar stock of two heats both of which were aluminum treated and whose compositions are as follows:

Carbon, per cent	Manganese, per cent	Phosphorus, per cent	Sulfur, per cent	Silicon, per cent	Aluminum, lb. per ton
0.14	0.45	0.011	0.035	0.09	1.64
0.12	0.55	0.015	0.029	0.10	2.03

For a study of the higher silicon contents and the relation between silicon and aluminum additions, two induction furnace heats have been melted and rolled to bar stock. These heats contain:

Carbon, per cent	Manganese, per cent	Silicon, per cent
0.16	0.59	0.15
0.14	0.46	0.31

Each heat was split three ways. One ingot was tapped as silicon-killed with no aluminum added, the second was tapped after an addition of 1 lb. per ton of aluminum, and the third after a further addition giving a total of 2.4 lb. per ton of aluminum.

For all of these steels, grain coarsening characteristics will be determined, and creep resistance will be determined as heat treated to produce fine and coarse austenite grain sizes. As indicated to be necessary by the results, experiments to determine critical cooling rates for good creep resistance will be made.

To determine more completely the value of rimmed carbon-molybdenum steel, a heat should be prepared with a carbon content of about 0.15 per cent for direct comparison with killed carbon-molybdenum steels normally used. Tests should be run at both 850 and 1000 F.

It would be very interesting to determine whether by suitable heat treatment weld metal could be changed to a condition of poor creep resistance. If the good creep resistance is the result of the rapid cooling from the fusion condition, heating for 1 or 2 hr. just above the critical range should produce a change in creep resistance toward lower properties. Since the weld metals were silicon-killed, very fast creep rates would not be expected, but somewhat faster creep rates than shown in this report would be expected. If this can be accomplished, it would be of further interest to determine the effect of coarsening and normalizing of these weld metals.

A few further tests on the aluminum-killed nonaging steel may be warranted. Since water quenching from the coarsening temperature was proved necessary for obtaining good creep resistance in this steel, it would be interesting to determine the effect of water quenching from the temperature of 1875 F. which produces a fine austenite grain size and from which air cooling produced a relatively rapid creep rate.

It is planned to include some titanium-treated steels in the Project 18 program and two titanium-treated steels are now available for test. One steel (0.15 per cent carbon) was deoxidized with ferrocarbon titanium and calcium silicide with no aluminum added. The second steel (0.36 per cent carbon) was deoxidized with ferrocarbon titanium only. Their compositions are as follows:

Carbon, per cent	Manganese, per cent	Silicon, per cent	Phosphorus, per cent	Sulfur, per cent	Titanium, per cent
0.15	0.23	0.10	0.006	0.022	0.030
0.36	0.80	0.14	0.016	0.045	0.028

SUMMARY

Further experiments on the effect of heat treatment on creep resistance at 850 F. of a silicon-killed and a silicon-aluminum steel of the S.A.E. 1015 type were made. The creep resistance of the former is not changed much by a change in austenite grain or cooling rate from the coarsening temperature. The silicon-aluminum-killed steel which shows poor creep resistance in the fine-grain condition is greatly improved by coarsening and air cooling, and shows intermediate creep resistance as a result of slower and controlled cooling rates after coarsening. Both steels show creep resistance approaching that for fine-grain material when they had a short-time grain refining treatment subsequent to a previous coarsening treatment. Room temperature tensile and impact properties previously indicated for fine-grain material were likewise practically duplicated.

Coarsening followed by air-cooling of an aluminum-killed nonaging steel (2.8 lb. aluminum per ton) produced some improvement in creep resistance at 850 F., but not so much as was expected. This steel with a higher aluminum addition required water quenching from the coarsening temperature to produce the low creep rate obtained previously by air cooling of steels with lower aluminum additions.

The only moderate improvement in creep resistance at 850 F. obtained upon coarsening and air cooling of the British steel E along with its poor creep resistance in the fine-grain condition suggests that the 0.08 per cent silicon may be too low to provide the silicon-containing inclusions postulated necessary to produce good creep resistance.

Molybdenum added to rimmed steel improves the creep resistance at 850 F. as well as when added to killed steels. Only slight improvement in creep resistance resulted from coarsening. The presence of molybdenum in rimmed steel seems to offset in part the previous large effects on creep resistance owing to differences in deoxidation practice shown by plain carbon steels. Since the carbon-molybdenum steel tested contained only 0.06 per cent carbon, the true relationship of rimmed carbon-molybdenum steel to killed carbon-molybdenum steel will be shown when a rimmed carbon-molybdenum steel with about 0.15 per cent carbon has been tested so that direct comparisons can be made.

Plain-carbon and carbon-molybdenum weld metal, even though extremely fine-grain, showed excellent creep resistance at 850 and 950 F. It is probable that the rapid cooling that takes place during welding while producing an extremely fine grain also produces a near optimum size and dispersion of inclusions or carbides, and hence, good creep resistance.

The experiments herein described on plain-carbon steels give additional credence to the previously advanced hypothesis that it is the absence or presence of inclusions of various types and compositions whose size, mode, and degree of dispersion determine creep resistance. Deoxidation practice and heat treatment, and particularly the temperature of heat treatment (as indicated by austenitic grain size) and the cooling rates used, are important factors influencing creep resistance.

Differences in creep resistance shown could not be predicted from either structures or room temperature tension properties.

This report concerns progress in a long-time program of the joint committee in which study of the relative effects of variables on creep resistance will be continued. The program is inactive for the duration of the war because the testing equipment is being used 100 per cent on testing of materials of immediate interest to the Armed Services. The future work planned and steels available for the tests have been discussed in detail in the report. It is hoped the work can be resumed in the near future.

APPENDIX II

CORRELATION OF SHORT- AND LONG-TIME ELEVATED TEMPERATURE TEST METHODS

(Project No. 25)

Introduction and Object

For almost two decades the long-time creep characteristics of materials have been a widely used criterion of their strength at elevated temperatures. However, their determination remains a tedious and costly process.

In the meantime a variety of shorter time tests has been proposed, each one intended to provide an adequate criterion of high-temperature performance or to be an actual prognosticator of creep characteristics. Lacking coordinated test data, engineers have never been able to agree that any of them achieves its purpose. Therefore, in 1940 the Joint Research Committee on Effect of Temperature on the Properties of Metals instituted Project 25 having the following twofold objective:

Primary or Quantitative Object.—To examine short-time high-temperature testing methods in terms of their ability to forecast long-time (creep) test results.

Secondary or Qualitative Object.—To examine short-time high-temperature testing methods in terms of their ability to distinguish between materials of different long-time (creep) characteristics.

Conclusions

Examination of the data from ten types of short-time tests on carbon steel K20 at 850 F. and on carbon-molybdenum steel K22 at 850 and 1000 F. led to the following conclusions in respect to the objects of the investigation:

1. From a quantitative standpoint, the tests were not able to predict long-time (creep) strength accurately and consistently. However, several tests showed sufficient promise in this direction to warrant further study.
2. In all cases but one, the strength values from short-time tests were in the same order as the creep strengths. In other words, all tests but the dynamic hot hardness test were able to distinguish between materials of different long-time (creep) strengths.

Recommendation

It is recommended that the sustained-load tension test, the Hatfield time-yield test, the DIN(DVM) test, and possibly a short-time relaxation test be further investigated as to their ability to predict creep strength values.

Procedure

Laboratories operating high-temperature testing equipment were invited to take part in the investigation. The following organizations participated with one or more test methods:

Bethlehem Steel Co.
Climax Molybdenum Co.
Crane Co.
Crucible Steel Co.
Edward Valve Co.
General Electric Co.
Lunkenheimer Co.
Midvale Co.

U. S. Naval Engineering Experiment Station
United States Steel Corp.
University of Michigan
Westinghouse Electric and Manufacturing Co.
Wm. Powell Co.

Several additional laboratories were prevented from participating by the increased demands on their facilities resulting from the war.

A plain carbon and a carbon-molybdenum steel in the form of bars, heat treated to obtain a high degree of uniformity and stability of properties, were distributed among the cooperating laboratories. Tests on the plain carbon steel were confined to 850 F. while the carbon-molybdenum steel was studied at both 850 and 1000 F. The tests conducted were of both short- and long-time classification and may be listed as follows:

Short-Time Tests:

1. Hot hardness
2. Standard short-time tension
3. Constant strain rate tension
4. Sustained-load tension
5. Stress-rupture
6. Hatfield time yield
7. DIN (DVM)
8. Barr and Bardgett
9. Step-down relaxation (flow rate)
10. Constant-strain relaxation

Long-Time Test:

1. Constant-stress creep

It should be recognized that some of the short-time tests listed above, including the step-down relaxation test and the constant-strain relaxation test, might be considered more or less long-time tests, as will be explained in the description of each short-time test method. Most of the short-time tests determine values based on higher deformation rates from higher stresses than are obtained from creep tests or from short-time testing periods of the long-time tests.

In addition to the results of the present cooperators, a considerable number of test properties were taken from the literature on steel K20.[1] The long-time (creep) properties came from this source.

The long-time properties of steel K22 were determined by the University of Michigan through a project sponsored by the joint committee. The University also acted as Secretary in carrying on correspondence relating to the tests and for assembling and correlating data.

MATERIALS INVESTIGATED

A 0.35 per cent carbon steel, designated K20, and a 0.50 per cent molybdenum steel, designated K22, were available for the testing program. The K20 material was the same as has been used previously for numerous other committee tests. It was completely described in the February, 1936, *Transactions* of the A.S.M.E. (**1**).[2] The K22 material was prepared for Project 25 by the Bethlehem Steel Co. A complete description of steel K22 is presented as Appendix A to this report, and a summary description of the two materials is given in Table I.

Both materials were products of 100-ton basic open-hearth furnaces. The ladle deoxidation of K20 was with 50 per cent ferrosilicon and 1.2 lb. of aluminum per ton. For K22 50 per cent ferrosilicon and 1.6 lb. of aluminum per ton were added in the ladle.

The test material in each case was rolled to 1-in. round bar stock and heat treated to give uniformity of properties. The uniformity was checked by means of Brinell hardness and room temperature tension tests on each bar.

---

[1] See "List of Published Reports with Reference to Tests on 0.35 per cent Carbon Steel K20," Report of Joint Research Committee on Effect of Temperature on the Properties of Metals, Appendix II, *Proceedings*, Am. Soc. Testing Mats., Vol. 40, p. 159 (1940).

[2] The boldface numbers in parentheses refer to the bibliography for steel K20 on p. 212. The numbers used are the same as those assigned to the various papers in the "List of Published Reports with Reference to Tests on 0.35 per cent Carbon Steel K20," *loc. cit.*

RESULTS

Physical properties have been determined in tests which vary from very short-time hot-hardness and tension tests to standard tension creep tests of 1000 hr. duration. The data obtained are summarized in the following sections. In so far as possible the values given are exactly as presented by the cooperators' reports. Certain tests were continued for time periods in excess of those which could properly be classified as short-time tests. In these cases, data have been selected from the early portion of the test for use in evaluating both the long-time (creep) behavior of the two alloys and the longer time results from the test.

TABLE I.—CHEMICAL COMPOSITION, GRAIN SIZE AND HEAT TREATMENT OF K20 AND K22 STEELS.

Material	Chemical Composition, per cent						McQuaid-Ehn Grain Size
	Carbon	Manganese	Phosphorus	Sulfur	Silicon	Molbydenum	
K20 (**1**).....	0.35	0.55	0.016	0.03	0.19	...	6 to 8
K22..........	0.16	0.66	0.015	0.027	0.24	0.53	6 to 8

HEAT TREATMENT

K20(**1**)......	Heated to 1550 F. in 2 hr., held 1 hr., furnace cooled to 1000 F. and then air cooled. Reheated to 1280 F. in 4 hr., held 2 hr., furnace cooled to 1000 F. and then air cooled. Cold straightened and reheated to 950 F. and air cooled. The above treating cycle was repeated with the cold straightening operation eliminated.
K22..........	Heated to 1650 F., held 1⅔ hr. and air cooled. Reheated to 1200 F., held 2 hr. and air cooled. Machine straightened. Stress relieved at 1200 F. for 2 hr. and air cooled.

ROOM TEMPERATURE PHYSICAL PROPERTIES

Material	Tensile Strength, psi.	Yield Strength, 0.2 per cent Offset, psi.	Elongation in 2 in., per cent	Reduction of Area, per cent	Brinell Hardness Number
K20 min..........	68 000	39 500[a]	36.5	62.3	128
max. (**1**)......	70 000	42 900[b]	39.0	65.8	131
avg...........	[c]	[c]	[c]	[c]	[c]
K22 min..........	66 000	45 500	35.0	72.9	131
max..........	68 500	49 000	40.0	75.1	137
avg..........	67 200	47 500	36.2	74.3	134

[a] Obtained from tests made in 1944.
[b] Minimum yield strength between 0.1 and 0.5 per cent offset.
[c] Not available.

TABLE II.—HOT HARDNESS DATA.

Material	Source of Data	Type of Test	Temperature, deg. Fahr.	Hardness Number
K20	E	Dynamic	850	95 Equivalent Brinell[a]
			900	95 Equivalent Brinell[a]
			950	105 Equivalent Brinell[a]
			1000	110 Equivalent Brinell[a]
	F	Vickers	80	152 D.P.H.[b]
			800	131
			850	120
			900	109
			950	93
			1000	82
			1050	74
			1100	67
			1150	60
			1200	56
			1250	49
			1300	43
			1350	39
K22	E	Dynamic	850	95 Equivalent brinell[a]
			900	105
			950	105
			1000	115
	F	Vickers	80	149 D.P.H.[b]
			800	140
			850	134
			900	128
			950	126
			1000	119
			1050	111
			1100	103
			1150	95
			1200	86
			1250	74
			1300	63

[a] First of two determinations which checked.
[b] Average of two or three determinations.

During the course of the investigation many cooperators accumulated test results which were not directly applicable to the subject of this investigation. Since such information may be valuable to other aspects of the joint committee's activities, these have been included as an Appendix.

Short-Time Tests:

All data for each test method have been summarized in tabular form and where possible are also presented graphically. A brief description of the test methods and procedure modification of the contributors is included.

Hot Hardness Tests.—The test of shortest duration which was considered a possible criterion of long-time properties was the determination of the hardness of the two steels at the test temperatures. Hardness determinations over a range in temperature were made by two methods.

Dynamic hot hardness tests were made in a guillotine type machine in which a drop hammer, fitted with exchangeable 10-mm. steel balls, slides vertically along two polished steel guides. The samples were heated, removed from the furnace, and placed in the tester, and the hammer dropped on them (**az**).[3] The size of the impression was measured and converted to "equivalent Brinell hardness" by means of an experimental calibration curve. Duplicate $\frac{1}{2}$-in. thick disks were held at temperature one hour before testing. The results obtained are given in Table II. The increase in hardness with temperature was unexpected, and the tests were repeated with check results.

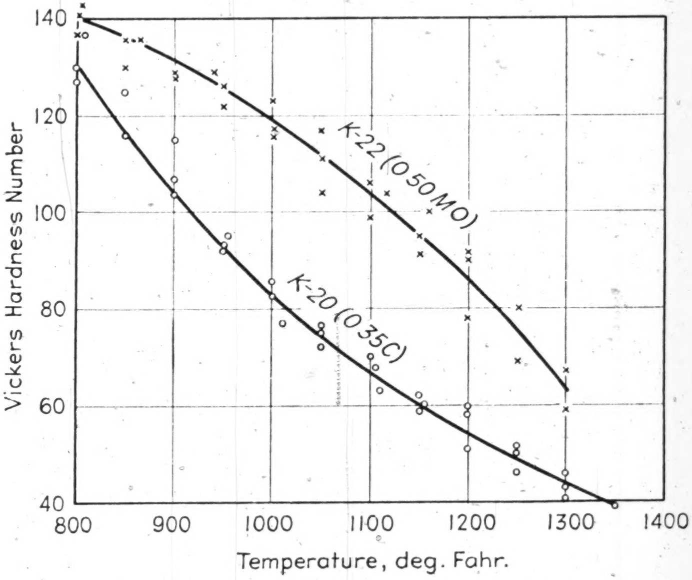


FIG. 1.—Effect of Temperature on the Vickers Hardness of K20 and K22 Steels.

Small samples of both K20 and K22 steels were heated in a vacuum attachment for a Vicker's hardness tester; a series of impressions was made at 50 deg. intervals at temperatures from 800 to 1350 F., the sample cooled to room temperature, and the impressions measured. The report presented diamond pyramid hardness numbers for two or three impressions at each temperature—their averages and curves. These curves of hardness *versus* temperature are shown in Fig. 1, and the average values given in Table II. The hardness numbers used for the comparison table are those defined by the curves of Fig. 1.

---

[3] The boldface letters in parentheses refer to the reports and papers listed in the references appended to this report, see p. 213. These are references which do not refer to steel K20.

TABLE III.—SHORT-TIME TENSION TEST PROPERTIES OF K20 AND K22 STEELS AT 850 AND 1000 F.[a]

Material	Source of Data[a]	Temperature, deg. Fahr.	Tensile Strength, psi.	Offset Yield Strength, psi.		Yield Point, psi.	Proportional Limit, psi.	Elongation, in 2 in., per cent	Reduction of Area, per cent	Modulus of Elasticity psi.
				0.1 per cent offset	0.2 per cent offset					
K20	**(1)**	850	46 350	18 500	20 200			49.0	79.2	
			45 700	18 000	19 800			49.0	79.3	
	(1)	850	45 500	19 500	20 500		16 500	49.0	80.1	
			45 125					51.0	80.5	
	(1)	850	45 175	17 500	19 375		6 250	48.5	80.2	
			44 600	16 800	18 750		5 000	48.5	80.4	
	(1)	850	40 500	18 500	......		11 000	52.0	81.5	
			46 400	17 400	......		8 000	50.0	80.8	
			42 500	17 750	19 750		11 000			
	(1)	850	42 800				15 000	49.0	79.8	
	(1)	850	40 200	16 500	18 000		10 000	59.4	84.0	
			43 500	17 250	18 750		12 500	55.2	82.3	
			43 900	18 250	19 500		12 500	53.6	81.8	
	(1)	850	41 500	17 600	18 600		10 100	54.4	82.9	
			42 400	18 000	19 800		13 000	56.7	82.4	
	H	850	44 300	18 500	20 350		12 000	48.1	80.0	
	B	850	44 500	15 900	......		8 000	51.6	80.5	23 800 000
	D	850	48 150		21 000		12 500	50.0	79.5	21 600 000
	Minimum	...	40 200		18 000			48.1	79.2	
	Maximum	...	48 150		21 000			59.4	84.0	
	Average	...	44 060		19 640			51.7	80.9	
K22	B	850	60 500	24 700		27 500	18 500	31.8	76.4	24 500 000
			59 500	28 500		30 000	15 500	27.4	78.5	23 200 000
			59 200	24 500		28 000	15 500	27.5	77.4	23 500 000
			58 000	23 900		27 500	16 000	31.3	78.6	25 400 000
	G	850	59 000		26 000		22 500	35.0	78.7	
			57 500		28 500		25 250	32.0	78.4	
	I	850	56 000					34.0	78.0	
	J	850	57 200(a)		27 600			35.5	79.8	
			57 000(b)		28 750			35.0	79.4	
			57 000(c)		26 650			33.5	78.0	
			57 750(d)		26 650			36.5	76.5	
	A	850	57 000	25 000			15 000	36.5	79.2	
			57 000	24 500			15 000	37.0	78.8	
	H	850	57 300	24 000	26 500		18 000	32.9	78.3	
	K	850	58 500	26 250	29 250		19 500	34.0	78.7	
	D	850	60 500		27 500		20 000	36.0	78.5	24 300 000
	Minimum		56 000		26 000			27.4	76.4	
	Maximum	...	60 500		29 250			37.0	79.8	
	Average	...	58 060		27 500			33.5	83.6	
K22	G	1000	45 500		27 750		22 500	32.5	84.3	
			46 500		26 750		24 500	31.5	83.2	
		1000	45 600					37.0	84.5	
	B	1000	48 800	24 000			16 000	31.0	82.7	21 000 000
			48 800	24 000			17 000	33.7	82.8	19 700 000
	H	1000	47 100	24 300	26 500		17 000	38.3	83.3	
	K	1000	49 250	25 800	28 000		15 500	33.0	83.3	
	J	1000	47 750(e)		32 400			39.5	82.5	
			47 500(f)		29 600			40.0	83.3	
	D	1000	46 750		26 500		15 000	36.0	83.5	22 800 000
	Minimum	...	45 500		26 500			31.0	82.5	
	Maximum	...	49 250		32 400			40.0	84.5	
	Average	...	47 360		28 210			35.2	83.3	

---

[a] The capital letter symbols have been used to indicate the laboratories of the organizations listed at the beginning of this report under the heading "Procedure;" the symbols bear no relation to the order in which they are listed. The boldface numbers and letters in parentheses throughout these tables refer to the papers and reports appended to this paper.

TABLE III.—Continued

Tension Testing Procedures.

Source of Data[a]	Type of Extensometer	Sensitivity	Testing Speed for Stress-Strain Data	Tensile Strength Head Testing Speed
D	Martens mirror	0.00001 in. in 2 inches	5000 to 8000 psi. per min.	0.25 in. per min.
H	......	......	0.000225 in. per inch per min.	0.25 in. per min.
B	Martens-Tuckerman	0.000002 in.	1 min. increments per 2000 sq.in.	0.25 in. per min.
A	A description of testing procedure was not submitted.			
I	2-in. gage length by 0.357-in. diameter specimens were stressed at a uniform rate of 7.5 in. per inch per hr. in a hydraulic tensile machine equipped with a pacing disk control.			
J	Templin-Peters stress-strain recorder	......	(*a*) 0.1 in. per min.; head speed 0.25 in. per min. (*b*) 0.08 in. per min.; head speed 0.27 in. per min. (*c*) 0.02 in. per min.; head speed 0.04 in. per min. (*d*) 0.01 in. per min.; head speed 0.03 in. per min. (*e*) 0.06 in. per min.; head speed 0.22 in. per min. (*f*) 0.06 in. per min.; head speed 0.22 in. per min.	
K	Modified Martens mirror	0.000003 in. per inch	2500 psi. in 30 sec.	0.3 in. per min.
G	External	0.001 in.	......	......

The Vickers test indicates a higher hot hardness for steel K22 than for K20. The shape of the curve was also different, showing considerably less effect of temperature on hardness for the molybdenum than for the carbon steel. The increase in hardness with increasing temperature, by the dynamic method, is an interesting finding since the static Vickers test showed a decrease with temperature.

Standard Short-Time Elevated-Temperature Tension Tests (A.S.T.M. E 21–43).[4]—Tests are conducted with specimens 0.505 in. in diameter in a furnace maintaining a uniform temperature over the gage length of the specimen. After thermal equilibrium has been established at the temperature desired for a test, a series of load and extensometer readings are taken under increasing load until the yield strength has been passed. The extensometer is then generally removed and the test continued to fracture.

The data submitted are presented in Table III. The values for cooperator I were not intended to be in accordance with E 21–43, but the data have been included because they are comparative. The testing procedures are summarized at the end of Table III. The tensile strength and ductility values are believed to show a greater variation than can be ascribed to the nonuniformity of these materials.

Controlled Strain Rate Tension Tests.—In the controlled strain rate test, test bars are subjected to a constant rate of strain which is generally continued until fracture occurs. The rates of strain may be varied from those of very rapid tests lasting a fraction of an hour to rates approaching those obtained in creep tests. The data obtained may include ultimate strength, yield strength, ductility, and time for fracture.

In laboratory I the specimens, held at constant temperature (plus or minus 2 F.), were extended at a uniform rate by means of a motor-driven gear chain. Interchangeable gears permitted strain rates of 1.0, 0.1, 0.01, and 0.001 in. per inch per hour. The stress was derived by observations of the extensions of a weigh bar, the strain by calculation of the rate of straining and the elapsed time. Tests were made at the faster strain-rate of 7.5 in. per inch per hour in a hydraulic testing machine equipped with a pacing mechanism which permitted control of the rate of straining. The specimens used for all tests had a uniform gage length of 2 in. and a diameter of 0.357 in. In addition to the data included in Table IV, stress-strain curves were shown in the report together with typical photomicrographs showing the types of fracture.

---

[4] 1943 Supplement to Book of A.S.T.M. Standards, Part I, p. 104.

TABLE IV.—CONTROLLED STRAIN RATE TENSILE DATA FOR K20 AND K22 STEELS AT 850 F. AND 1000 F.

Source of Data	Strain Rate, in. per inch per hr.	Ultimate Strength, psi.	Elongation in 2 in., per cent	Reduction of Area, per cent	Time for Fracture, hr.	Type of Fracture
			K20 at 850 F.			
(11)	39	49 500[a]				
	2.13	42 000				
	0.247	36 000				
	0.0428	32 500				
	0.00166	24 500				
			K22 at 850 F.			
I	7.5	56 000	34.0[b]	78.0[b]	0.05	Trans-granular
	1.0	54 000	31.5	77.5	0.33	
	1.0	52 300	31.0	78.5	0.33	
	0.1	55 200	33.5	78.0	3.7	
	0.1	54 800	35.0	77.0	3.6	
	0.01	53 000	41.0	77.0	43.0	
	0.001	51 000	40.0	66.0	426.0	
O	1.73	56 000				
	0.049	55 500				
	0.00082	54 500				
			K22 at 1000 F.			
I	7.5	45 600	37.0[b]	84.5[b]	0.05	Trans-granular
	1.0	42 500	37.5	79.0	0.38	
	1.1	40 900	42.0	67.7	4.4	
	0.01	40 000	31.5	40.0	35.0	Inter-granular
	0.01	38 000	32.0	39.0	34.5	
	0.001	32 700	19.0	20.0	236.0	
	0.001	33 500	20.0	15.5	239.0	
	1.73	45 000				
	0.049	39 000				
	0.00082	34 500				
			K22 at 850 F.			
	Head Speed, in. per min.					
G	0.25	57 200	35.0	79.8	0.3	
	0.27	57 000	35.0	79.4	0.3	
	0.04	57 000	33.5	78.0	2.0	
	0.03	57 750	36.5	76.5	3.66	

[a] Ultimate strengths estimated from graphs in reference paper.

[b] Specimens were 0.357 in. in diameter with a 2-in. gage length.

The tests by laboratory J were conducted in a tension testing machine on standard 0.505-in. diameter specimens, with the head speed varied after exceeding the yield stress, as described in the description of tension testing procedures in Table III.

Constant strain rates were obtained by a constant speed screw mechanism, and the loads were measured by the load indicator of a hydraulic tension testing machine at the laboratory of cooperator O. Elongations were measured by observing platinum strips on the gage length with micrometer microscopes

A series of stress-strain curves for K20 steel at several rates of strain are given in reference (11). The yield points and the ultimate strengths increased with rates of strain. The ultimate strengths given in Table III were estimated from the stress-strain curves in the reference paper. In addition the paper presented a method of predicting long-time creep rates. This involved the correction of the measured loads for reduction of area so as to obtain true stresses, and then plotting the true stress *versus* the logarithm of plastic strain rate at definite amounts of strain. A series of curves were thereby established which could be extrapolated to the creep test strain rate range. This extrapolation could best be used by determining one long-time creep test strain rate and using it to aid extrapolation of the short-time constant-strain rate test results.

All data are assembled as Table IV and in so far as possible are shown graphically in Fig. 2. The question then arose as to what test result to use to correlate with creep strengths. For the purposes of this report it was decided to extrapolate the curves to creep test strain rates. For this reason the curves in Fig. 12 have been extended to strain rates of 0.0000001 in. per inch per hour (creep rate of 0.01 per cent per 1000 hr.) and the creep strengths added.

TABLE V.—SUSTAINED LOAD TEST RESULTS.

Material	Temperature, deg. Fahr	Stress, psi.	Constant (Minimum) Strain Rate, per cent per hr.	Estimated Creep, psi.		Stress, 0.01 per cent per 1000 hr.
				Temperature, deg. Fahr.	0.1 per cent per 1000 hr.	
K20....	1000	15 000	1.29	850	8 000	5 400
	1000	7 500	0.012			
	1050	7 500	0.054			
	1100	7 500	0.21			
	1150	7 500	0.79			
	1300	3 000	0.33			
K22....	1000	30 000	0.095	850	39 000	28 000
	1050	25 000	0.23	1000	11 000	7 800
	1100	25 000	7.1			
	1100	15 000	0.083			
	1150	15 000	1.07			
	1200	15 000	8.25			
	1200	7 500	0.068			
	1250	7 500	0.37			
	1300	7 500	2.36			
	1300	3 750	0.052			

The curve for steel K20 at 850 F. extrapolates well to the creep strengths. Cooperator I's curve at 1000 F. extrapolates to the creep test results, but the curve for cooperator O does not. Neither cooperator's curve agrees with creep tests at 850 F. for steel K22 after extrapolation.

As another means of presenting the data of cooperator I, Fig 3 has been prepared to show the relation between rates of strain and time for fracture. On the basis of this figure, fracture would occur in 100,000 hr. for steel K22 at 1000 F. under a rate of 0.01 per cent per 1000 hr. while at 850 F. the time for fracture is indicated to be considerably greater than 100,000 hr.

Sustained Load Tension Test.—The sustained load tension test is based on the relationship between temperature and rate of strain. Under a given load, the constant strain rate of the secondary

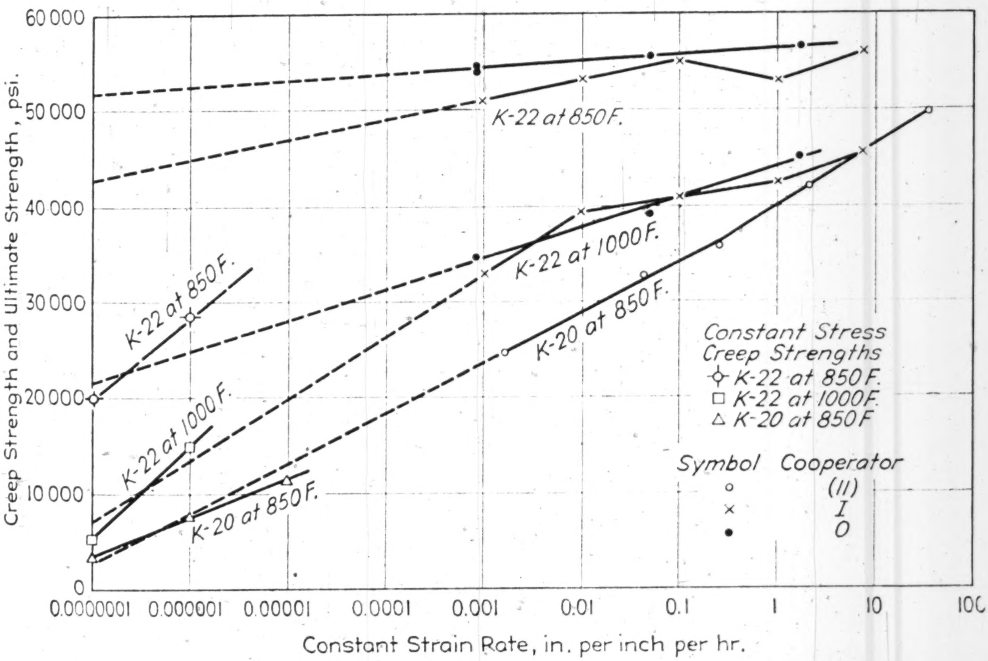


FIG. 2.—Extrapolation of Constant Strain Rate Tensile Data to Creep Test Strain Rates.

stage of creep is a function of temperature such that a plot of creep rate on a logarithmic scale *versus* reciprocal absolute temperature yields a straight line. This relationship may be used to correlate long-time creep tests with short-time sustained load tests (**aj, ap**).

several different stresses so that it is possible, by extrapolation and interpolation, to estimate creep strengths at different temperatures.

The tests reported in Table V were conducted in a hydraulic tensile machine equipped with a load maintainer and a stress-strain recorder. The creep rate reciprocal absolute temperature curves as given by the cooperator are shown by Figs. 4 and 5. The estimated creep strengths in Table V were obtained from these curves. The cooperator also submitted curves for creep strength *versus* temperature which are reproduced and compared with constant stress creep test results in Fig. 6.

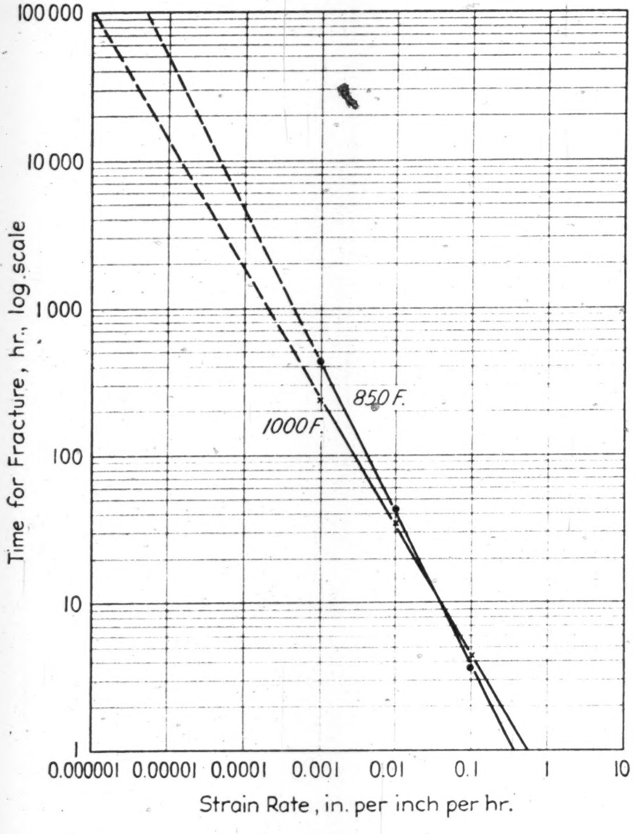


FIG. 3.—Effect of Strain Rate on the Time to Fracture for K22 Steel at 850 and 1000 F.

The conditions of sustained load testing are identical with those of creep testing in that strain readings are obtained over a period of time under constant load and temperature. The conditions of stress and temperature are such as to yield a second stage creep rate of about 1 per cent per hour. Ordinarily a number of tests are conducted over a suitable range of temperatures at

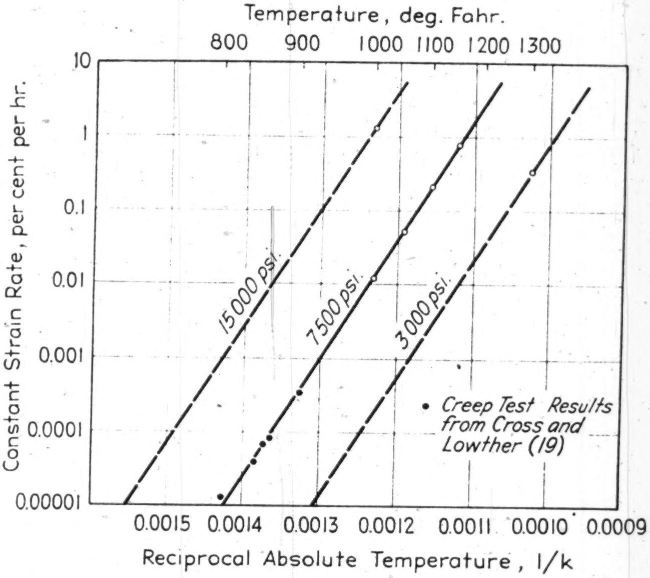


FIG. 4.—Sustained Load Tension Tests Strain Rates *versus* Reciprocal Absolute Temperature for K20 Steel.

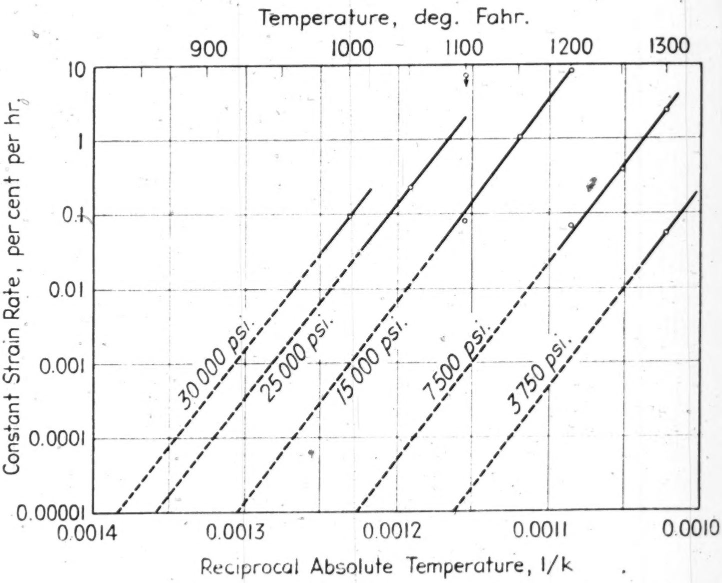


FIG. 5.—Sustained Load Test Strain Rates *versus* Reciprocal Absolute Temperature for K22 Steel.

Creep test results for steel K20 have been included in Fig. 4 by the cooperator to show the excellent correlation. The extrapolation to creep test results for K22 steel is not so good, although the curves of Fig. 5 could have been drawn equally well with a somewhat greater slope and would then have given results which would have agreed much more closely with the creep test data.

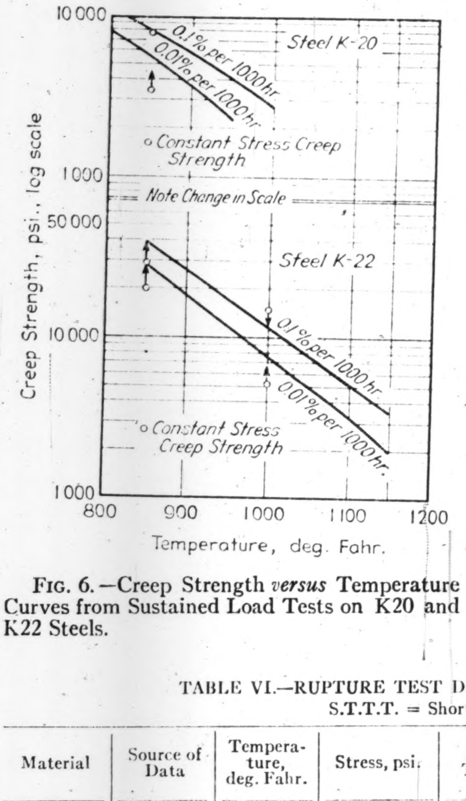


FIG. 6.—Creep Strength *versus* Temperature Curves from Sustained Load Tests on K20 and K22 Steels.

Rupture Tests.—The rupture test is conducted under the same conditions as creep tests except that time elongation data are not usually observed, and the stresses employed are selected so as to cause fracture in a series of time periods from a few minutes to as many hours as are deemed necessary. Fracture times and stresses are plotted logarithmically producing a straight line which frequently breaks so that two intersecting straight lines are obtained. Such breaks are generally attributed to surface or structural instability of the metal **(al, am)**.

The data presented in Table VI were all obtained by running tests in tension testing machines under various constant stresses and observing the time to fracture. These data are shown graphically in Fig. 7.

The rupture strength of the molybdenum steel K22 is almost twice that of the carbon steel on the basis of the 10-hr. strength at 850 F., and is about 9000

TABLE VI.—RUPTURE TEST DATA FOR K20 AND K22 STEELS.
S.T.T.T. = Short-time tension test.

Material	Source of Data	Temperature, deg. Fahr.	Stress, psi.	Rupture Time, hr.	Elongation in 2 in., per cent	Reduction of Area, per cent	Stress for Rupture in 10 hr., psi.
K20	H	850	44 300	S.T.T.T.	48.1	80.0	33 000
			40 000	0.25	57.2	79.5	
			37 000	1.51	51.4	78.7	
			35 000	4.15	52.9	78.4	
			35 000	4.30	51.1	78.0	
			32 000	10.50	52.3	78.5	
			31 000	22.60	54.0	78.0	
K20	(21)	850	45 050	S.T.T.T.	52.5	79.5	32 500
			40 000	0.40	56.0	79.5	
			36 000	1.67	56.0	79.5	
			32 500	8.30	57.5	79.2	
			31 000	13.92	53.0	78.4	
K22	H	850	57 300	S.T.T.T.	32.9	78.3	56 000
			56 000	2.70	36.0	76.4	
			56 500	5.75	36.5	77.7	
			55 500	32.0	Not fractured	Not fractured	
K22	H	1000	47 100	S.T.T.T.	38.3	83.3	42 000
			44 000	0.87	39.6	82.2	
			43 000	1.50	40.0	80.1	
			42 500	5.55	43.5	70.1	
			42 000	14.40	35.8	58.1	

TABLE VII.—HATFIELD TIME-YIELD DATA FOR K22 STEEL AT 850 AND 1000 DEG. FAHR.

Material	Source of Data	Temperature, deg. Fahr.	Stress, psi.	24–72 hr. Deformation, in. per inch	Time-Yield Stress, psi.
K22.....	D	850	15 000	0.000045	17 000
			17 000	0.000042	
			20 000	0.000080	
	K		20 000	0.000085	18 000
			22 500	0.000140	
			25 000	0.000190	
			27 500	0.000390	
	D	1000	4 000	0.000032	6 000
			6 000	0.000044	
			8 000	0.000090	
	K		5 500	0.000014	10 000
			7 500	0.000022	
			10 000	0.000045	
			12 500	0.000094	

psi. higher at 1000 F. than the carbon steel at 850 F.

Hatfield Time Yield Test.—The Hatfield time yield test is run in the same manner as a creep test except that it requires only 72 hr. Sufficient deformation data must be recorded to determine the extension during the first 24 hr. and the extension during the time period between 24 and 72 hr. (**q, w, ac**). The time-yield stress is defined as the maximum stress which will not produce an extension exceeding 0.5 per cent in the first 24 hr. nor any measureable extension at an average rate greater than 10^{-6} in. per inch per hour during the next 48

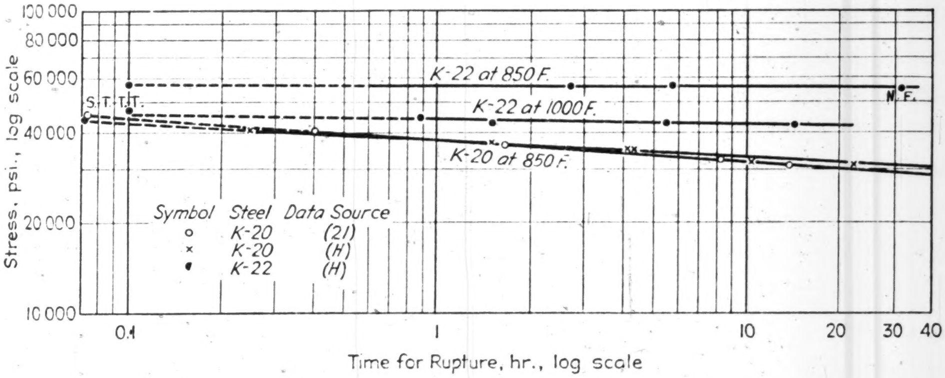


FIG. 7.—Stress-Rupture Time Curves for K22 (0.50Mo) and K20 (0.35C) Steels.

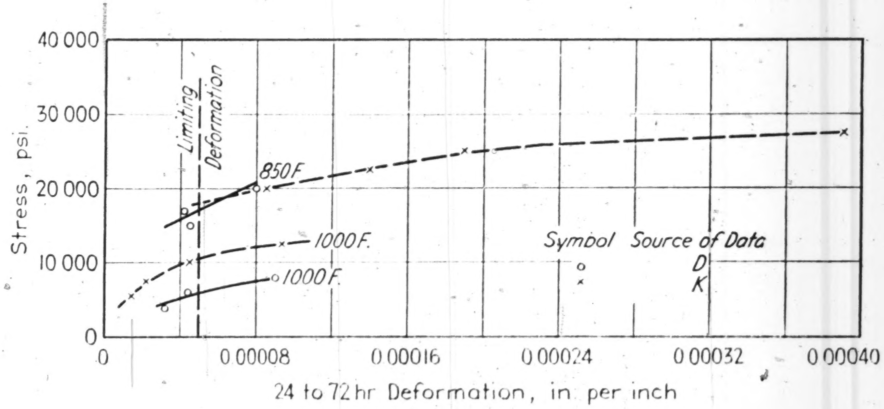


FIG. 8.—Hatfield Time-Yield Curves for K22 Steel at 850 and 1000 F.

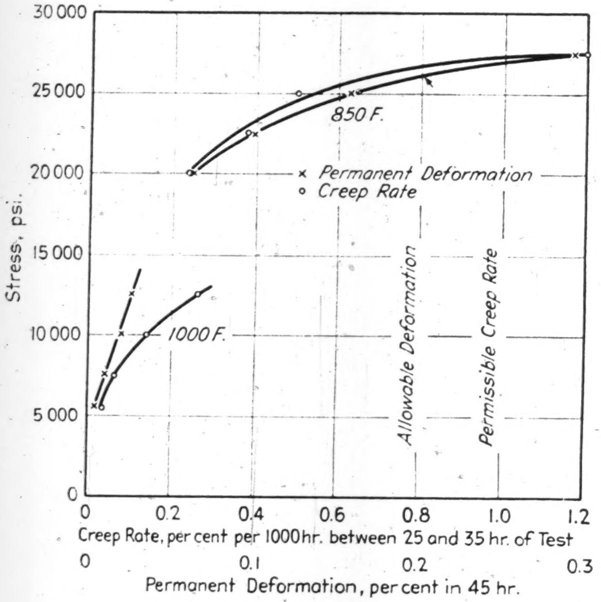


FIG. 9.—Graphical Determination of Permissible DIN (DVM) Creep Stress for Steel K22 at 850 and 1000 F.

hr. In practice several tests are run and the data extrapolated to the stress causing 0.00050 in. deformation between the twenty-fourth and seventy second hr. The limiting extension has been variously defined by Hatfield as 0.048 per cent and 0.05 per cent during the last 48 hr. of testing (y, al). The difference between these two causes only a slight difference in the time-yield stress.

The data reported by laboratory K were obtained in a creep test unit by observing the extension of the standard specimens at 1-hr. intervals during the first 72 hr. of the tests. The data from laboratory D were obtained in a Losenhausen creep testing machine. The specimen was 7 in. in length with a 4-in. gage length. A modified Martens mirror type extensometer was used, and a beam of light having a magnification of 1000 was recorded photographically.

The results obtained by the two laboratories were limited to steel K22. As is shown by Table VII and Fig. 8 the time-yield stresses from the two sources agreed at 850 F. but not at 1000 F.

TABLE VIII.—BARR AND BARDGETT TEST DATA FOR K20 AND K22 STEELS AT 850 F. AND 1000 F.

Material	Source of Data	Temperature, deg. Fahr.	Elasticity Factor	Initial Stress, psi.	Final Stress, psi.	Decrease in Stress, psi.	Limiting Creep Stress, psi.
K20...	L	850	1.8	16 000	11 500	4500	5 500
			1.8	12 000	9 200	2800	
			1.5	8 800	7 400	1400	
K22...	J			14 050	13 900	150	13 400
				24 000	21 500	2500	
				34 200	23 650	5550	
	L		1.9	24 000	20 800	3200	11 100
			2.1	20 400	17 000	3400	
			1.4	16 000	14 200	1800	
	J	1000		12 500	11 000	1500	6 000
				15 350	13 600	1750	
				24 500	21 000	3500	
				32 600	26 500	6100	
	L		1.9	20 400	15 600	4800	9 100
			2.0	16 000	11 500	4500	
			1.7	12 000	10 100	1900	

DIN (*DVM*) *Test.*—This test is based on the assumption that the creep resistance will be within "conventional limits" if the creep rate between the twenty-fifth and thirty-fifth hours does not exceed 1 per cent per 1000 hr. and the permanent deformation does not exceed 0.2 per cent after 45 hr. The test is run in the same manner as standard creep tests except that it is necessary to run tests for only 45 hr. Several tests are run under different stresses at each temperature and the permissible stress determined by interpolation.

The following time-elongation data were obtained at the time the creep tests were conducted on steel K22:

Temperature, deg. Fahr.	Stress, psi.	25–35 hr. Creep Rate, per cent per 1000 hr.	45 hr. Permanent Deformation, per cent	Permissible Stress, psi.
850	20 000	0.24	0.062	26 000
	22 500	0.38	0.100	
	25 000	0.50	0.157	
	27 500	1.20	0.292	
1000	5 500	0.035	0.006	....
	7 500	0.065	0.010	
	10 000	0.140	0.021	
	12 500	0.265	0.025	

These data are presented graphically in Fig. 9 to show the determination of the permissible stress. At 850 F. both the creep rate and permanent deformation are close to the allowable limits, the latter being slightly lower. Both the permanent deformations and creep rates are far below the permissible values at 1000 F., and a permissible stress cannot be determined from the data. The results at 1000 F. do indicate, however, that the permissible stress from this test would be much higher than is indicated by the creep tests.

Barr and Bardgett Test.—The Barr and Bardgett test is an accelerated creep test of the relaxation type (**ab, ae**). The specimen is 6 in. long by 0.25 in. in diameter and is tested in a heavy frame with a weigh bar in the loading system for estimating stress. Several tests are conducted at the same temperature but with different initial stresses, and the decrease in stress with each test is determined at the end of 48 hr. Decrease in stress is plotted against initial stress and a line drawn which is extended to the initial stress axis. The stress, defined by the intersection of the curve and initial stress axis, will not decrease measurably for the 48-hr. test period and is termed the "limiting creep stress."

Laboratory L's equipment was not a duplicate of the original Barr and Bardgett equipment (**ag**). The minimum average rate of creep which would cause a readable change in stress in 48 hr. was approximately 0.2 per cent per 1000 hr., as estimated from the physical constants of the unit. In reporting the data, the points obtained by the highest loading were neglected because it was thought that the stress was above the proportional limit and produced inconsistent data. The testing conditions, other than temperature surveys, were not reported by cooperator J.

The reported results are summarized in Table VIII, and the graphical determinations of limiting creep stress are shown by Figs. 10 and 11. The test revealed pronounced differences between the two steels, even though the agreement between the two laboratories was not very good.

Step-Down Relaxation Test (*Flow Rate Test*).—This test is run with the equipment ordinarily used for constant stress creep tests and is a step-down creep test with nearly constant extension of the specimen (**12**). After the specimen is brought up to temperature, the stress is applied in increments, and the elastic extension is noted as each increment is applied. As soon as a predetermined total extension has been reached, the stress is reduced and the relaxation test begins. Creep occurs at constant stress to the predetermined extension limit after which the stress is again reduced, and so on in successive steps. Each step gives a creep rate corresponding to the applied load, and the entire process approximates the performance of a bolt in an unyielding flange, with the entire elasticity of the system being included within the member in which the plastic action occurs.

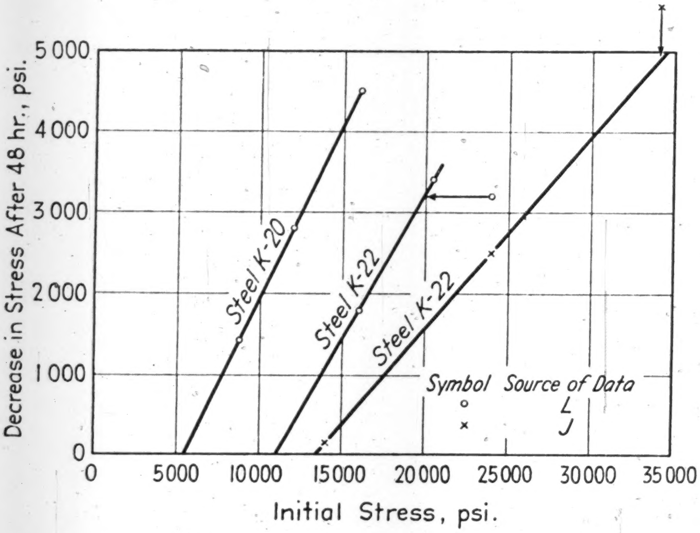


FIG. 10.—Barr and Bardgett Curves for Steels K20 and K22 at 850 F.

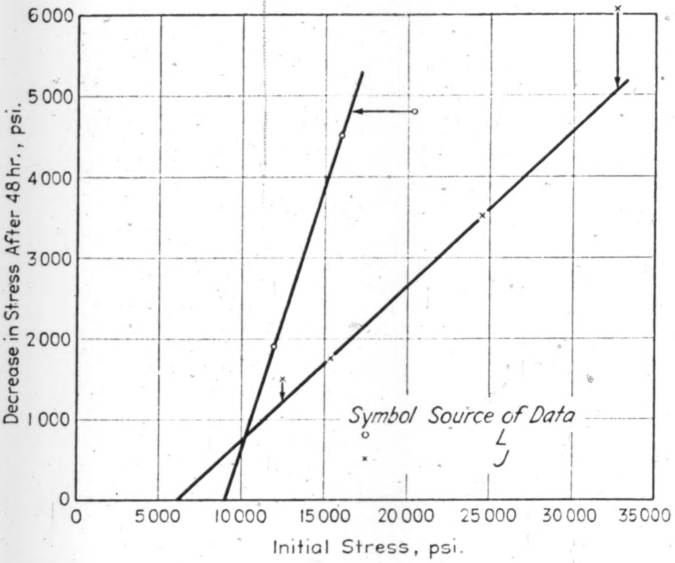


FIG. 11.—Barr and Bardgett Curves for Steel K22 at 1000 F.

It has been recommended that the

TABLE IX.—STEP-DOWN RELAXATION TEST (FLOW RATE TEST) DATA FOR K20 STEEL AT 850 F. AND K22 STEEL AT 1000 F.

Source of Data	Stress, psi.	Creep Rate, per cent per 1000 hr.	Time Interval Under Stress, hr.	Estimated Residual Stress after 10,000 hr., psi.
K20 Steel at 850 F.[a]				
(12)......	10 000	....	30	1842
	7 500	0.238	30–120	1700(23)
	5 500	0.090	120–290	
	4 000	0.015	290–1225	
	3 000	0.003	1225–3670	
K22 Steel at 1000 F.[b]				
N........	24 000	....	1 min.	
	19 000	....	0.7	
	15 000	2.3	0.7–7.4	
	12 000	0.35	7.4–44.4	
	10 000	0.15	44.4–108	
	8 000	0.058	108–270	
	6 000	0.031	270–635	
	5 000	0.018	635–885	
	4 000	0.0122	885–1315	
	3 000	0.008	1315–2040	
	2 000	0.004	2040–3450	

[a] Elastic + plastic extension limited to 0.15 per cent; modulus of elasticity 20,000,000.

[b] Elastic + plastic extension limited to 0.2 per cent; modulus of elasticity 22,700,000.

test be of several thousand hours duration for reliable results. Step-down relaxation (flow rate) data were available for steel K20 at 850 F. (12) and a test was conducted on K22 steel at 1000 F. for this investigation. The results obtained, as creep rates for the steps in stress, are summarized in Table IX, and the flow rate stresses for 0.01 and 0.10 per cent per 1000 hr. creep rates are shown by Fig. 12 to be:

Steel	Temperature, deg. Fahr.	Flow Rate Creep Strength, psi.	
		0.01 per cent per 1000 hr.	0.10 per cent per 1000 hr.
K20.....	850	3700	6200
K22.....	1000	3500	9200

The flow rate creep characteristics of K20 steel at 850 F. were not greatly different from those from standard creep tests, according to Fig. 12. A rather

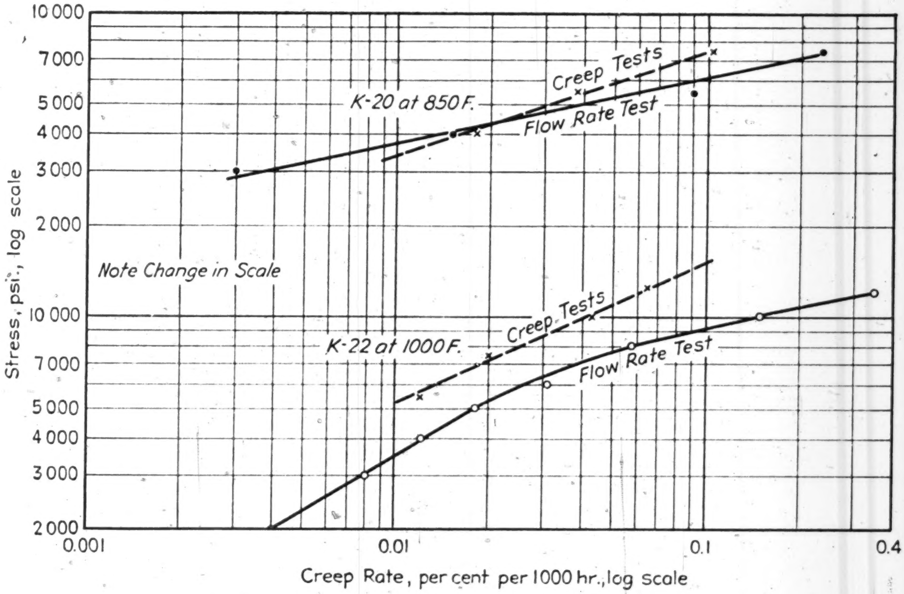


FIG. 12.—Comparative Stress-Creep Rate Curves for Step-Down Relaxation (Flow-Rate) Tests and Creep Tests for K20 and K22 Steels.

wide difference was discovered between the two methods in the case of K22 steel at 1000 F. These comparisons are, however, in both cases based on the results of long-time tests.

In order to predict standard single-step creep strengths from short duration flow rate tests, the test on K20 steel would have had to be extended to 1225 hr. to obtain a reliable indication of the final curve. This would still have represented a saving of about 2000 hr. over the testing time of the single-step creep tests. The flow rate-stress curve for K22 steel changed slope to a marked degree after 635 hr. so that a total of 3000 hr. testing was needed to establish the curve reliably. It is interesting to note that if the test had been discontinued after the 8000 psi. step (270 hr. of testing) the flow rate-stress curve would have extrapolated very closely to the creep test 0.01 per cent per 1000 hr. strength.

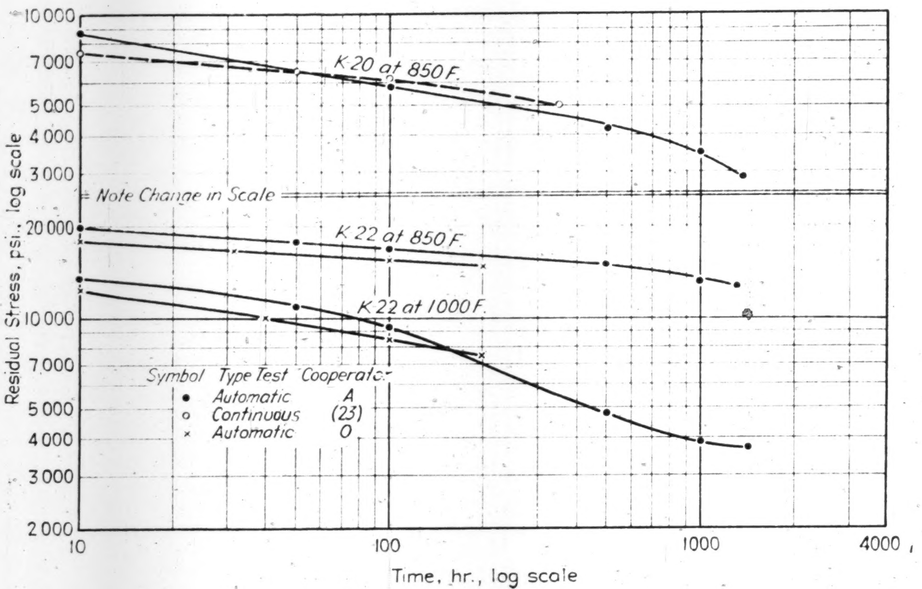


FIG. 13.—Residual Stress-Time Curves for Constant Strain Relaxation Tests on K20 and K22 Steels at 850 and 1000 F.

Constant Strain Relaxation Tests.—Tests in which the total deformation of the specimen is limited to a selected constant amount of strain by the removal of stress as relaxation occurs simulate the service conditions of bolts. The results of these tests are a curve of residual stress *versus* time of testing. The time required for the test varies from a few hours in the case of the Barr and Bardgett test, previously described, to several thousand hours. The equipment used for these tests varies from a simple bolt assembly to elaborate equipment designed to remove stress continuously so as to maintain precisely the desired constant strain. Variations of the assembly of the equipment make it possible to vary the elastic follow up of the system, and thus simulate varying elasticity in flange applications.

Laboratory A described its test equipment as designed to decrease the stress automatically to compensate for small increments of creep in the specimens. The specimen is loaded by means of a tank full of oil. Oil is released from the tank by a magnetic valve actuated by electrical relays connected to an extensometer mounted on the specimen within the furnace. The extensometer is secured to the specimen gage length, and this eliminates the necessity for an elasticity factor for the straining system.

TABLE X.—CONSTANT STRAIN RELAXATION TEST DATA.

Source of Data	Type of Test	Initial Stress, psi.	Residual Stress, psi., after indicated period, hr.					End of Test		Estimated Residual Stress, psi. per 10,000 hr.
			10	50	100	500	1000	Time, hr.	Residual Stress, psi.	
					K20 Steel at 850 F.					
(23)	Continuous	10 000[b]	7 500	6 500	6 000			350	5 000	1 260[a]
A	Automatic	15 000	8 750	6 500	5 750	4 200	3 500	1 380	2 900	
(13)	"Bolt"	5 000 10 000 20 000		4 200 5 475 4 950	(average of two tests)					
M	"Bolt"	40 000 40 000					4 600 5 100			
(23)	Automatic	15 000[b] 10 000[b] 5 000[b]	7 000 6 500 3 200	... ...	4 300 4 000 2 500					1 000
					K22 Steel at 850 F.					
A	Automatic	25 000 35 000[c]	20 250 29 250	17 750 25 250	16 800 23 000	14 500 18 800	14 000 18 400	1 320 1 465	13 750 18 250	
O	Automatic	23 300	17 750	16 000	15 400			200	14 800	
M	"Bolt"	40 000 40 000					10 500 10 800			
					K22 Steel at 1000 F.					
A	Automatic	20 000	13 750	10 750	9 250	4 650	3 800	1 440[d]	3 750	
O	Automatic	19 200	12 250	9 600	8 500	...	...	200	7 500	
M	"Bolt"	20 000 20 000					6 600 6 600			

[a] Specimen was reloaded at 10,000 lb. after 350 hr., and this value is based on second curve.
[b] Estimated residual stresses from graphs in reference papers.
[c] Same specimen as 25,000 psi. test which was reloaded after 1320 hr. to 35,000 psi.
[d] Test was continued beyond this time period, but data have not been reported.

Laboratory O kept the gage length of the test specimen at a constant extension by automatically decreasing the load through extensometers and electrical controls to the loading mechanism. This was the equipment used for the "automatic" tests reported in reference **23**. Relaxation test results for steel K20 were given in reference **23** from equipment in which continuous readings on a "weigh bar" at room temperature indicate the elastic stress effective at any time. The machine simulates the action of a bolt in a flange possessed of considerable elasticity so that the stretching of the specimen only partially results in relaxation of the initial stress. The elasticity of the system was five times that of the specimen where plastic action occurred.

In another laboratory, a test block of the same steel as the test specimen and of approximately 30 times the cross-section of the specimen is assembled at room temperature with the specimen as an actual bolt under a measured stress

(13). The assembly is placed in a test furnace and then removed after the desired time at temperature, and the actual change in stress at room temperature determined.

TABLE XI.—CONSTANT STRESS CREEP DATA FOR K20 STEEL AT 850 F.

Source of Data	Stress, psi.	Creep Rate, per cent per 1000 hr., for indicated periods, hr.				
		500–1000	750–1250	1000–2000	2000–3000	3000–4000
(12)	7 500	0.122	0.107	0.091	0.079	0.072
	5 500	0.047	0.038	0.031	0.024	0.021
	4 000	0.019	0.018	0.015	0.012	0.010
(20)	Range in creep rates from eight tests at 7500 psi.					

	Creep Rate, per cent per 1000 hr., for indicated periods, hr.							
	250	500	750	1000	1500	2000	2500	3000
Range	0.150 to 0.287	0.121 to 0.160	0.094 to 0.125	0.070 to 0.125	0.065 to 0.097	0.066 to 0.094	0.066 to 0.090	0.065 to 0.082
Average	0.198	0.142	0.113	0.099	0.082	0.080	0.076	0.073

Source of Data	Stress, psi.	Creep Rate, per cent per 1000 hr., at indicated periods, hr.										
		500	1000	1400	2000	3000	4000	5000	6000	7000	8000	9000
(10)	7 500	0.12	0.12	0.10	0.09	0.09	0.075	0.025	0.07	0.06	0.06	0.06
	8 000	0.17	0.15	0.13	0.11	0.10	0.09	0.075	0.075	0.075	0.085	0.095
(2)	9 000	0.39	0.335	0.26								
	10 000	0.56	0.54									

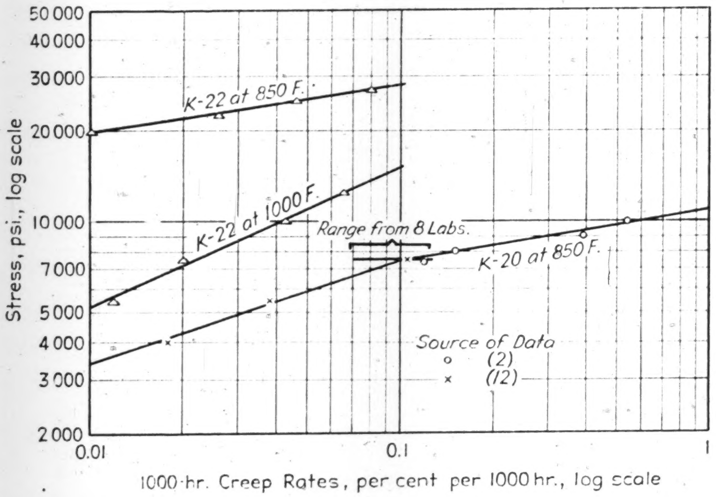


FIG. 14.—Stress-Creep Rate Curves for 1000 hr. Rates Obtained from Steel K20 at 850 F. and Steel K22 at 850 and 1000 F.

The residual stress-time curves are reproduced in Fig. 13. The residual stresses at various periods, as shown by the curves of Fig. 13 and the "bolt" test, are compared in Table X. The results from this test are influenced by variations in the initial stress with consequent variations in the constant strain of the tests. The various types of equipment gave reasonably similar results for the same initial stresses. All of the results reflect the higher strength of the molybdenum steel K22.

Long-Time (Creep) Tests (A.S.T.M. E 22 - 41).[5]—Constant stress creep tests are conducted by applying a tensile stress to a specimen at the desired temperature and observing the deformation of the specimens over a period of time. Such tests are conducted for at least 1000 hr. and in many cases for longer periods. In general, the rate of elongation of the specimen decreases with time during the first part of the test—the period of so-called "first stage creep." Eventually the rate becomes constant. This is the creep rate customarily reported and is designated as "second stage creep." In many cases, however, the creep rate may still be decreasing at the end of 1000 hr., and in such cases it is customary to report the average rate over the last 500 hr. of the test. Likewise, if the stress is high enough, the minimum rate may be exceeded in 1000 hr., and the rate of elongation may again increase during the so-called "third stage creep."

At least three, and preferably four, tests are conducted at each temperature, and the second stage creep rates determined. These usually plot on logarithmic coordinates as straight lines for the purposes of interpolation or extrapolation to the stresses for specified creep rates known as creep strengths. These rates are variously referred to as follows:

0.0000001 in. per inch per hour,
0.000001 per cent per hr.,
0.01 per cent per 1000 hr., or
1.0 per cent per 100,000 hr.,

0.000001 in. per inch per hour,
0.0001 per cent per hr.,
0.10 per cent per 1000 hr., or
1.0 per cent per 10,000 hr.

Constant Stress Creep Tests on K20 Steel.—Sufficient constant stress creep test results for the purposes of this investigation were available in the literature for steel K20 at 850 F. These creep rates are summarized in Table XI. The creep rates at 1000 hr. are plotted logarithmically against stress in Fig. 14 for the purpose of determining 0.01 and 0.10 per cent per 1000 hr. creep strengths. The rates for this time period were selected because they represent the results obtained from standard 1000-hr. tests. It should be noted, however, that the data in Table XI show that the creep rates decreased for time periods up to at least 4000 hr. The differences in creep strength for different time periods are as follows:

Testing Time, hr.	Stress for Indicated Creep Rates, psi.	
	0.01 per cent per 1000 hr.	0.10 per cent per 1000 hr.
1000	3400	7600
4000	4000	8200

Reference (19) presents the results of 20,000 hr. of testing at 7500 psi. where again a period of 4000 hr. was required before the creep rate became constant. In this case the constant rate was 0.06 to 0.07 per cent per 1000 hr.

K22 Constant Creep Test Properties.—The results of the creep tests at the University of Michigan are given in the following table:

Temperature, deg. Fahr.	Stress, psi.	Creep Rate, per cent per 1000 hr. over indicated time intervals		
		500 to 1000 hr.	800 to 1300 hr.	1500 to 2000 hr.
850	20 000	0.010	....[a]	0.010
	22 500	0.040	0.026	....
	25 000	0.058	0.046	....
	27 500	0.15	0.08	....
1000	5 500	0.013	0.012	....
	7 500	0.019	0.020	....
	10 000	0.045	0.043	0.044
	12 500	0.070	0.065	0.062

[a] Not reported because of an unexplained increase in rate from 900 to 1200 hr.

---

[5] 1942 Book of A.S.T.M. Standards, Part I, p. 930.

TABLE XII.—COMPARATIVE SHORT-TIME AND LONG-TIME (CREEP) TEST STRENGTH AT 850 F. AND 1000 F.

Test	Strength Values			Average Creep Strength Prediction Factor					
				0.1 per cent per 1000 hr.			0.01 per cent per 1000 hr.		
	K20 850 F.	K22 850 F.	K22 1000 F.	K20 850 F.	K22 850 F.	K22 1000F.	K20 850 F.	K22 850 F.	K22 1000F.
HOT HARDNESS TESTS									
(a) Dynamic (equivalent Brinell)	95	95	115	1.6	0.4	1.1	1.5	0.3	1.2
(b) Vickers, d.p.h.n.[a]	116	136	119	1.6	0.5	0.9	1.6	0.3	1.1
STANDARD SHORT-TIME TENSILE TESTS									
(a) Tensile strength (average)	44 060	58 060	47 360	1.6	0.6	0.9	1.6	0.4	1.1
(b) Yield strength (average)	19 640	27 500	28 210	1.4	0.6	1.0	1.4	0.3	1.3
CONSTANT STRAIN RATE TENSILE TEST									
(a) Ultimate strength for 0.1 per cent per 1000 hr. strain rate[b]	7 500	45 000	13 500	0.7	1.1	0.7	...	...	...
	...	52 500	25 000	...	1.3	1.2	...	...	...
(b) Ultimate strength for 0.01 per cent per 1000 hr. strain rate[b]	2 500	42 500	7 000	...	...	...	0.3	1.0	0.6
	...	51 750	21 500	...	...	...	...	1.2	1.9
SUSTAINED LOAD TENSILE TEST									
(a) 0.1 per cent per 1000 hr. creep strength[b]	8 000	39 000	11 000	1.0	1.3	0.7	...	...	...
(b) 0.01 per cent per 1000 hr. creep strength[b]	5 400	28 000	7 800	...	...	...	1.1	0.9	1.0
STRESS RUPTURE TEST									
(a) 10 hr. rupture strength	33 000	56 000	42 000	1.4	0.7	0.9	1.4	0.4	1.2
HATFIELD TIME YIELD TEST									
(a) Time yield strength	...	17 000	6 000	...	1.0	0.7	...	0.8	0.9
	...	18 000	10 000	...	1.0	1.2	...	0.8	1.6
DIN (DVM) TEST									
(a) Permissible stress	...	26 000	...	...	0.9	...	...	1.3	...
BARR AND BARDGETT TEST									
(a) Stress for no relaxation after 48 hr.	5 500	13 400	6 000	1.4	0.9	0.8	1.4	0.6	1.0
	...	11 100	9 100	...	0.8	1.2	...	0.5	1.6
STEP-DOWN RELAXATION (FLOW RATE) TEST									
(a) Stress for creep rate of 0.1 per cent per 1000 hr.	6 200	...	9 200	1.1	...	0.9	...	...	...
(b) Stress for creep rate of 0.01 per cent per 1000 hr.	3 700	...	3 500	...	...	...	1.2	...	0.8
CONSTANT STRAIN RELAXATION TESTS									
(a) 50 hr. Residual Stress									
"Bolt" test	4 875	...	...	0.9	...	...	0.9	...	...
Continuous test	6 500	...	...	1.2	...	...	1.2	...	...
Automatic test	6 500	17 750	10 750	1.2	0.9	1.0	1.2	0.6	1.3
Automatic test	...	16 000	9 600	...	0.8	0.9	...	0.5	1.2
(b) 1000 hr. residual stress									
"Bolt" test	4 850	10 650	6 600	1.4	0.8	1.0	1.5	0.6	1.4
Automatic test	3 500	14 000	3 800	1.0	1.1	0.6	1.1	0.8	0.8
CONSTANT STRESS CREEP TESTS (1000 hr.)									
(a) Stress for creep rate, 0.1 per cent per 1000 hr.	7 600	28 500	15 000						
(b) Stress for creep rate, 0.01 per cent per 1000 hr.	3 400	20 000	5 200						

[a] d.p.h.n. = diamond pyramid hardness number.

[b] Obtained by considerable extrapolation.

NOTE: All stress values are in pounds per square inch. Two values for the same test represent results from different laboratories.

$$\text{Average creep strength prediction factor} = \frac{\text{test strength}}{\text{creep strength}} \div \text{Average ratio of test strengths to creep strengths}$$

For example, the factors for the standard short-time tensile strengths were calculated as follows:

1. Ratios of test strength to creep strengths:

   (a) K20 at 850 F. $= \dfrac{44060}{7600} = 5.8$

   (b) K22 at 850 F. $= \dfrac{58060}{28500} = 2.0$

   (c) K22 at 1000 F. $= \dfrac{47360}{15000} = 3.1$

2. Average ratio of test strengths to creep strengths $= \dfrac{5.8 + 2.0 + 3.1}{3} = 3.633$

3. Calculation of factors:

   (a) K20 at 850 F. $= \dfrac{5.8}{3.63} = 1.6$

   (b) K22 at 850 F. $= \dfrac{2.0}{3.63} = 0.6$

   (c) K22 at 1000 F. $= \dfrac{3.1}{3.63} = 0.9$

The creep rates, over the time interval from 800 to 1300 hr., were plotted logarithmically, as shown in Fig. 14. This period was selected because the creep rates did not become reasonably constant before that time. The curves define the following creep strengths:

Temperature, deg. Fahr.	Stress for Indicated Creep Rates, psi.	
	0.01 per cent per 100 hr.	0.10 per cent per 1000 hr.
850	20 000	28 500
1000	5 200	15 000

It was observed that the creep rates decreased with time under the higher stresses, particularly at 850 F. The indications are, therefore, that the reported creep strengths are lower, as in the case of steel K20, than those which would have resulted if tests of several thousand hours had been conducted.

CORRELATION OF SHORT-TIME TEST AND LONG-TIME (CREEP) TEST STRENGTHS

All of the strength values obtained from the various tests have been assembled in Table XII. In every case except the dynamic hot hardness test, the various tests gave results which were in the same order as the creep strengths. Within the limits of this investigation, then, the short-time tests were able to distinguish between materials of different long-time strength. It should be recognized that this investigation was not broad enough in scope to define the limits within which this finding would hold.

The accuracy of prediction of creep strength by the short-time tests has been evaluated on the basis of the ratio of the various short-time test results to the corresponding creep strengths. In order to give easily comparative figures "creep strength prediction factors" have been computed by averaging the ratios. It is important to understand that the factors do not directly convert to creep strength but rather are comparative numbers only.

On the basis of these factors, it appears that the sustained load tension test, the Hatfield time-yield test, and the DIN (DVM) test are best able to predict one or the other of the creep strengths. The various relaxation tests may have some merit in predicting the 0.1 per cent per 1000 hr. creep strength. The results, therefore, indicate that the above-mentioned tests offer sufficient promise toward fulfilling the object of predicting long-time behavior to warrant further study.

DISCUSSION OF RESULTS

The problem of predicting long-time (creep) properties of metals at elevated temperatures involves the following principles:

1. A short-time test result which is either the creep strength or some value which can be used to predict the creep strength.
2. The ability to predict and allow for any metallurgical changes which may occur during long-time service and thereby change the creep strength.

It is quite possible that some of the tests considered in this investigation could be developed to predict creep strengths, provided that the materials would remain essentially unchanged during long-time exposure to stress and temperature. The fact that most materials do not remain stable is a limiting factor on even the standard 1000-hr. creep test.

The metallurgical changes which may occur in the metals can be grouped into two classifications:

1. Strain hardening caused by testing stresses far above those ordinarily applied in creep testing. Such conditions may well, and probably do, result in actual tests being run on metallurgically different material than are the lower stress creep tests.

2. Structural changes, such as recrystallization, spheroidization, precipitation reactions, and surface attack which occur under the combined influence of time, temperature, and stress.

The tests considered in this investigation may be grouped into the following types:

1. *Empirical tests that on the basis of more or less long-time tests measure some value of the material that may be related to the creep strength.*—This classification includes hot hardness, short-time tension, constant strain-rate tension, stress-rupture, Barr and Bardgett, and the various relaxation tests.

Consideration of the test results indicates that these tests fail to predict long-time behavior accurately and consistently because they either over-stress the material, measure a quantity which bears no relation to the creep strength, or fail to take into consideration possible metallurgical changes.

2. *Tests which measure some early portion of the standard creep curve.*—This classification includes the Hatfield time-yield and the DIN (DVM) tests. These methods may be reliable provided the material is stable at the temperature in question. That is, the tests are suitable provided the limits set up by the tests actually hold for the material. It is certain that different materials have different time-deformation characteristics. Likewise these tests cannot predict structural and surface instability that occurs only after prolonged time periods.

3. *Short-time Creep Tests.*—This classification has been set up for the sustained load tension test. It is possible that the step down relaxation (flow rate) test should be included.

In the sustained load test actual creep rates are obtained by measuring the strain rates of tests conducted under the same conditions as rupture tests. The stresses are all high in comparison with the actual long-time creep test stresses. The test, however, attempts to relate second stage creep rates determined from short-time, high-stress tests with the second stage rates from creep tests. The short-time tests at higher temperatures introduce temperature as a variable which may in some degree anticipate the metallurgical changes which occur only after prolonged time at the lower temperatures. The data indicated that the test has a limited reliability at low temperatures.

The flow rate test measures creep rates under intermittently decreased loads. The initial stresses are usually higher than those of creep tests, but not to the extent of those in many of the other tests. This test cannot take into account instability caused by prolonged testing and is a compromise with the amount of initial strain hardening.

The test results accumulated for the steels K20 and K22 are probably as near ideal as is possible, since both materials are quite stable for the time periods involved at the temperatures considered. Therefore many of the test results correlate very well with creep properties. At least they all gave strength values in the same order as the creep test.

The best correlations between long- and short-time tests were obtained from the tests which measured actual creep rates. These include:

Sustained load tensile test
Hatfield time-yield test
DIN (DVM) test

These tests show the most promise as short-time tests for predicting long-time behavior. They should not, however, be applied to materials which will be unstable under long-time conditions without further confirmation.

Furthermore, this classification of tests should not be construed to reflect adversely on the other tests which give perfectly good results for a particular purpose.

Reproducibility:

The question of reproducibility of results deserves consideration in appraising the results of this investigation. This factor enters into all of the data reported. For instance, a simple value such as tensile strength shows as much as 20 per cent variation at one temperature for one material. In other cases, different laboratories obtained widely different results from the same test. In so far as could be determined both technique and judgment in handling test data may have influenced results. This finding perhaps indicates that any short-time tests cannot be expected to yield precise predictions of creep test results except under extremely careful testing conditions Conversely, too much emphasis may have been placed on actual creep strengths which are sensitive to many metallurgical variations in materials.

The committee recommends that the three tests which appear most promising be given further study through a more thorough survey on other materials and at other temperatures, in order to determine their sensitivity to variations in heat treatments and uniformity of materials.

Although the results of this investigation do not emphasize the point, there is a great need for a short-time test which will predict structural changes which markedly affect long-time properties. The eventual development of a reliable short-time test must necessarily evaluate this factor.

APPENDIX A

DETAILED DESCRIPTION OF 0.50 PER CENT MOLYBDENUM STEEL K22

The 0.50 per cent Molybdenum steel K22 was furnished by the Bethlehem Steel Co. from Heat 2A377. This heat was a product of a 100-ton basic open-hearth furnace.

Manufacturing Practice:

Metallic Charge:

High phosphorus scrap	105 800 lb.
De-tinned scrap	25 300 lb.
High phosphorus beams	16 500 lb.
Ferro-molybdenum	440 lb.
Hot metal	117 300 lb.
Total	265 340 lb.

The following deoxidation practice was followed:

In Furnace:

Spiegel	1000 lb.
Pig-iron	4000 lb.
Spiegel	1000 lb.
14 per cent Ferro-silicon	200 lb.
14 per cent Ferro-silicon	1400 lb.
80 per cent Ferro-manganese	1400 lb.
67 per cent Silicon-Manganese	1400 lb.

In Ladle:

50 per cent Ferro-silicon	1600 lb.
Stick Aluminum	260 lb. (1.95 lb. per ton)

Thirty-inch corrugated ingots were used and teemed through a 1½-in. nozzle. The tapping temperature was 2895 F. and the teeming temperature 2700 to 2680 F.

All of the ingots (19) were moved after 4 hr., stripped, and charged hot into the soaking pits.

The bar stock for Project 25 was made from the fifth ingot. After 6 hr. heating this ingot was rolled to a 6½-in. square billet, converted to a 2½-in. square and buried to permit slow cooling. Surface inspection revealed this material to be entirely satisfactory from the standpoint of scale, visible defects, etc.

McQuaid-Ehn grain size and acid etch specimens revealed fine grain (6 to 8) sound material, and it was approved for rolling. 1300 lb. of the 2½-in. square billet stock was rolled to 1-in. round bar stock and yielded 30 bars 15 ft. long.

Chemical Composition:

The analyses reported by Bethlehem Steel Co. are given in the following tabulation:

	Chemical Composition, per cent					
	Carbon	Manganese	Phosphorus	Sulfur	Silicon	Molybdenum
Heat Analysis	0.17	0.67	0.015	0.028	0.25	0.51
Check	0.15	0.66	0.014	0.026	0.23	0.54

Heat Treatment:

The 1-in. bar stock was heat treated by normalizing and drawing according to the following schedule:

1. Heated to 1650 F., held for 1 hr. and 40 min., and air cooled,
2. Reheated to 1200 F., held for 2-hr. and air cooled,
3. Machine straightened, and
4. Reheated to 1200 F., held for 2 hr., and air cooled for stress-relieving.

Uniformity of Properties:

The 30 bars were stamped 1A to 30A and the opposite ends 1B to 30B. Six-inch lengths were cut from each end of each bar for room temperature tensile strength and Brinell determinations. Tension test specimens were machined with a 2-in. gage length, and 0.505-in. diameter, and subjected to tension tests using an autographic recorder. The test results are summarized as follows:

	Tensile Strength, psi.	Yield[a] Point, psi.	Proportional Limit, psi.	Elongation in 2 in., per cent	Reduction of Area, per cent	Brinell Hardness Number
Minimum	66 000	47 500	43 500	35	72.9	131
Maximum	68 500	53 000	52 500	38	75.1	137
Average	67 278	49 368	47 746	36.5	74.1	135
Maximum variation from average, per cent	1.90	7.36	9.95	4.11	1.62	2.96

[a] Drop of the beam yield point.

The following tabulation shows the bars grouped according to the maximum percentage variation of any property from the average of all the bars:

Maximum Variation, per cent	Bar Numbers
Less than 2	None
2–3	8, 13, 15, 18, 19, 21, 23, 25, 2
3–4	1, 3, 6, 7, 11, 16, 20
4–5	12
5–6	4, 10, 24, 27, 29, 30
6–7	17, 22, 26, 28
7–8	14
8–9	9
9–10	5

Bars Nos. 9 and 5 were discarded because of comparatively high deviation in proportional limit. After discarding these bars, the uniformity recalculated as follows:

	Tensile Strength, psi.	Yield[a] Point, psi.	0.2 per cent Offset Yield Strength, psi.	Proportional Limit, psi.	Elongation in 2 in., per cent	Reduction of Area, per cent	Brinell Hardness Number
Minimum	66 000	47 500	45 500	44 000	35.0	72.9	131
Maximum	68 500	52 000	49 000	51 000	38.0	75.1	137
Average	67 200	49 400	47 500	47 700	36.2	74.3	134.2
Maximum variation from average, per cent	1.93	5.27	4.21	7.76	4.97	1.88	2.38

NOTE: The individual stress-strain curves and tabulated values for each bar are filed with the records of Project 25 under the heading "Preparation of K22 Steel."

[a] Drop of the beam yield point.

APPENDIX B

CHEMICAL COMPOSITION OF PROJECT 25 STEELS

Two laboratories reported check chemical analyses of steels K20 and K22 in addition to the analyses originally supplied by the steel producers:

Steel	Source of Data	Chemical Composition, per cent								
		Carbon	Manganese	Phosphorus	Sulfur	Silicon	Nickel	Chromium	Molybdenum	Aluminum
K20	1	0.35	0.55	0.016	0.03	0.19	....	....	....	....
	A	0.34	0.55	0.011	0.025	0.19	....	....	none	0.06
	B	0.42	0.53	....	....	0.19	0.09	0.06	0.02	....
K22	C[a]	0.17	0.67	0.015	0.028	0.25	....	....	0.51	....
	C[b]	0.15	0.66	0.014	0.026	0.23	....	....	0.54	....
	A	0.16	0.63	0.020	0.016	0.24	....	....	0.53	....
	B	0.18	0.61	....	....	0.20	0.13	0.09	0.45	....

[a] Heat. [b] Check.

Consideration of these values led Project 25 committee to report the following analyses:

Steel	Chemical Composition, per cent					
	Carbon	Manganese	Phosphorus	Sulfur	Silicon	Molybdenum
K20	0.35	0.55	0.016	0.03	0.19	....
K22	0.16	0.66	0.015	0.027	0.24	0.53

APPENDIX C

ROOM TEMPERATURE PHYSICAL PROPERTIES OF PROJECT 25 STEELS.

Steel	Source of Data	Tensile Strength, psi.	Yield Point, psi.	Offset Yield Strength, psi.		Proof Stress, psi.	Proportional Limit, psi.	Elongation in 2 in., per cent	Reduction of Area, per cent	Brinell Hardness Number
				0.1 per cent	0.2 per cent					
K20	(1) Min.[a]	68 000					21 500	36.5	62.3	128
	Max.[a]	70 000					24 000	39.0	65.8	131
	A	66 900		46 000		45 000	40 000	41.0	64.5	
		66 600	...	...		...	...	41.0	66.0	
		66 600	...	45 000		45 000	38 000	42.0	66.0	
	B	69 000	...	...	39 500	...	...	34.5	64.2	
		69 500	...	...	41 500	...	...	34.0	62.8	
	D	69 000			46 000		45 000	38.5	66.5	
	I	68 600	...	...	42 800[b]	...	...	33.5	65.8	
		68 900	...	...	42 900[b]	...	...	31.5	66.2	
K22	C Min.[c]	66 000	47 500		45 500		44 000	35.0	72.9	131
	Max.[c]	68 500	52 000		49 000		51 000	38.0	75.1	137
	Avg.[c]	67 200	49 400		47 500		47 700	36.2	74.3	132
	A	67 500		50 000		49 000	40 000	40.0	74.6	
	D	66 750			50 350		50 000	39.0	75.5	
	L	67 000	48 000				45 000	37.5	74.5	134

[a] Based on 49 tests from 49 bars.
[b] Minimum yield strength between 0.1 and 0.5 per cent offset.
[c] Based on 56 tests from 28 bars.

REFERENCES

LITERATURE ON STEEL K20

The reference numbers are those given in the "List of Published Reports with Reference to Test on 0.35 Per Cent Carbon Steel K20" in *Proceedings*, Am. Soc. Testing Mats., Vol. 40, p. 159 (1940).

(1) "Short-Time Tensile Tests at 850 F. of the 0.35 Per Cent Carbon Steel Material K20." Progress Report by Subgroup D on Short-Time Tensile Tests, H. J. Kerr, Chairman, Joint Research Committee on Effect of Temperature on the Properties of Metals, *Transactions*, Am. Soc. Mechanical Engrs., Vol. 58, February, 1936, RP-58-4, p. 97.

(2) H. C. Cross and F. B. Dahl, "Long-Time Creep Tests of 18 Cr 8 Ni Steel and 0.35 per cent Carbon Steel," *Transactions*, Am. Soc. Mechanical Engrs., Vol. 58, February, 1936, RP-58-3, p. 91.

(10) H. C. Cross and J. G. Lowther, "Long-Time Creep Tests of 18 Cr 8 Ni Steel K19 and 9.35 C Steel K20," *Transactions*, Am. Soc. Mechanical Engrs., Vol. 59, July, 1937, RP-59-5, p. 439.

(11) A. Nadai and E. A. Davis, "Constant Strain-Rate Tests on 0.35 C Steel K20 at 850 F.," *Transactions*, Am. Soc. Mechanical Engrs., Vol. 59, July, 1931, RP-59-6, p. 447.

(12) E. L. Robinson, "A Relaxation Test on 0.35 C Steel K20," *Transactions*, Am. Soc. Mechanical Engrs., Vol. 59, July, 1931, RP-59-7, p. 451.

(13) N. L. Mochel, "Relaxation Tests on 0.35 C Steel K20 at 850 F.," *Transactions*, Am. Soc. Mechanical Engrs., Vol. 59, July, 1931, RP-59-8, p. 453.

(18) A. Nadai and J. Boyd, "Relaxation of Steels at Elevated Temperatures — A New Automatic Relaxation Machine," Abstract, *Journal of Applied Mechanics*, Vol. 5, September, 1938, p. A-118.

(19) H. C. Cross and J. G. Lowther, "Report on Long-Time Creep Tests of 0.35 per cent Carbon Steel (K20)," Appendix II, Report of Joint Research Committee on Effect of Temperature on the Properties of Metals, *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 121 (1938).

(20) C. L. Clark, "Report Covering Creep Tests on 0.35 per cent Carbon Steel (K20) at 850 F. under a Stress of 7500 psi.," Project No. 14, Appendix III, Report of Joint Research Committee on Effect of Temperature on the Properties of Metals, *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 130 (1938).

(21). A. E. White and C. L. Clark, "Report on Acceptability Tests for High Temperature Characteristics," Project No. 17, Appendix IV, Report of Joint Research Committee on Effect of Temperature on the Properties of Metals, *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 142 (1938).

(23) E. L. Robinson, "The Resistance to Relaxation of Materials at High Temperatures," Progress Report of Project 16, *Transactions*, Am. Soc. Mechanical Engrs., Vol. 61, August, 1939, p. 545.

PARTIAL LIST OF PAPERS PERTAINING TO SHORT-TIME HIGH-TEMPERATURE TEST METHODS

(a) E. N. Andrade, "On the Viscous Flow in Metals and Allied Phenomena."

(b) E. N. Andrade, "The Flow in Metals under Large Constant Stresses," *Proceedings*, The Royal Society, Vol. 90 (1914).

(c) P. Chevenard, "Sur la viscosité des aciers aux températures élevées," *Comptes Rendus*, Vol. 169, p. 712 (1919).

(d) P. Chevenard, "Alliages de nickel conservent leur rigidité dans un domaine étendu de température," *Comptes Rendus*, Vol. 175, p. 486 (1922).

(e) V. T. Malcolm, "Methods of Testing at Various Temperatures and Their Limitations," *Proceedings*, Am. Soc. Testing Mats, Vol. 24, Part II, p. 15 (1924).

(f) F. C. Lea, "Effect of Low and High Temperatures on Materials," *Proceedings*, Institution of Mechanical Engineers, Vol. 2, p. 1053 (1924).

(g) J. S. Brown, "Influence of the Time Factor on Tensile Tests Conducted at Elevated Temperature," *Journal*, Institute of Metals, Vol. 34, Part 2, p. 21 (1925).

(h) J. Cournot and K. Sasagawa, "Sur la viscosité a chaud de quelques alliages," *Comptes Rendus*, Vol. 181, p. 661 (1925); also *Revue de Métallurgie*, Vol. 22, p. 753 (1925).

(i) A. Pomp and A. Dahmen, "Development of a Short Test for the Determination of the Permanent Strength of Steel at Elevated Temperatures," *Mitteilungen aus dem Kaiser—Wilhelm Institute für Eisenforschung*, Düsseldorf, Vol. 9 (1926).

(j) H. Shoji, "On the Plasticity of Metals," Tokyo, Imperial University Science, Reports, Vol. 15, p. 426 (1926).

(k) H. Shoji and Y. Mashiyama, "On the Plasticity of Metals in High Temperatures," Tokyo, Imperial University Science, Reports, Vol. 15, p. 443 (1926).

(l) A. Michel and J. Cournot, "Constricution a l'étude de la viscosité a chaud," International Congress for Testing Materials, Amsterdam, Vol. 1, p. 397 (1937).

(m) A. Michel and M. Matte, "Variations des propriétés mécaniques des aciers et alliages avec la température," *Revue de Métallurgie*, Vol. 24, p. 200 (1927).

(n) P. Henry, "Recherches expérimentals sur les vitesses de deformation de métaux aux hautes températures," *Revue de Métallurgie*, Vol. 24, p. 421 (1927); also *Comptes Rendus*, Vol. 182, p. 761 (1927).

(o) W. Rohn, "Heat Resisting Alloys," *Proceedings*, International Association for Testing Materials, p. 389 (1927).

(p) P. Chevenard, "Les propriétés élastiques et visquerises des alliages," *Proces- Verbal*, Société Ingenieurs Civils de France, March 25, 1927.

(q) W. H. Hatfield, "The Application of Science to the Steel Industry," *Transactions*, Am. Soc. Steel Treating, pp. 109–110 (1928).

(r) W. H. Hatfield, discussion on paper by H. J. Tapsell on "The Fatigue Resisting Properties of 0.17 Percent Carbon Steel at Different Temperatures and at Different Mean Tensile Stresses," *Journal*, Iron and Steel Institute, Vol. 117, No. 1, (1928).

(s) "Rapid Tests," A note on Creep Tests, *Metallurgist*, Vol. 4, p. 82 (1928).

(t) L. Guillet, J. Galibourg, and M. Samsoen, "Sur les essais de traction a chaud," *Comptes Rendus*, Vol. 188, pp. 1205 and 1328 (1929).

(u) W. H. Hatfield, "The Response of Steel at Elevated Temperatures," *Journal*, West of Scotland Iron and Steel Institute, Vol. 36, p. 60 (1929).

(v) W. H. Hatfield, "Steels at Elevated Temperatures," *The Iron Age*, August 8, 1929.

(w) W. H. Hatfield, "Permanence of Dimensions under Stress at Elevated Temperatures," *Journal*, Iron and Steel Institute, (1930).

(x) "Symposium on Effect of Temperature on Properties of Metals," published jointly by American Society for Testing Materials and American Society of Mechanical Engineers (Issued as a separate publication) (1931).

(y) G. R. Brophy, "The Characteristics of Deformation of Steel Under Constant

Load at Elevated Temperatures," *Transactions*, Am. Soc. Steel Treating (1931).

(z) H. J. Tapsell, "Creep of Metals," London, H. Milford, Oxford University Press (1931).

(aa) A. Pomp and Walter Enders, "Accelerated Method for Determining Creep Limit," *Instruments*, Vol. 5, July, 1932.

(ab) W. Barr and W. E. Bardgett, "An Accelerated Test for the Determination of the Limiting Creep Stress of Metals, *Proceedings*, Institute of Mechanical Engrs., Feb. 19, 1932; also *The Engineer*, Feb. 26, 1932; also *Engineering*, March 4, 1932.

(ac) A. E. White and C. L. Clark, "Comparison of Single-Step Long-Time Creep Results with Hatfield's Time-Yield Stress," *Transactions*, Am. Soc. of Metals, Vol. 22, pp. 481–494 (1934).

(ad) P. D. Sale, "Compression Tests of Structural Steel at Elevated Temperatures," *Journal of Research*, Nat. Bureau Standards, Vol. 13, p. 713 (1934).

(ae) "Creep Resisting Steel," Samuel Fox and Co., Ltd., p. 24 (1935).

(af) M. Schmidt and H. Krainer, "Abgekürzte Bestimmung der Dauerstandfestigkeit bei veränderlicher Temperatur," *Mitterlungen des technischen versuchsamtes*, Vienna, Vol. 24, p. 5 (1935).

(ag) J. J. Kanter, "Interpretation and Use of Creep Results," *Transactions*, Am. Soc. Metals, Vol. 24, p. 870 (1936).

(ah) G. Welter, "Elastizitätsgrenze und Mikroverformungen bei dynamischen Beigenbeanspruchungen von Baustoffen bei hoken Temperaturer," *Zeitschrift für Metallkunde*, Vol. 28, p. 257 (1936).

(ai) A. E. White, C. L. Clark, and R. L. Wilson, "The Fracture of Carbon Steels at Elevated Temperatures," *Transactions*, Am. Soc. Metals, Vol. 25, p. 863 (1937).

(aj) J. J. Kanter, "The Problem of the Temperature Coefficient of Tensile Creep Rate," *Transactions*, Am. Inst. Mining and Metallurgical Engrs., Iron and Steel Division, Vol. 131, p. 385 (1938).

(ak) C. L. Clark, A. E. White, and G. J. Guarnieri, "A New Application for the Short-Time High-Temperature Tensile Test," *Transactions*, Am. Soc. Metals, Vol. 26, p. 1035 (1938).

(al) W. H. Hatfield, "Heat-Resisting Steels," *Engineering*, April 22, 1938.

(am) A. E. White, C. L. Clark, and R. L. Wilson, "Rupture Strength of Steels at Elevated Temperatures," *Transactions*, Am. Soc. Metals, Vol. 26, p. 52 (1938).

(an) R. H. Thielemann and E. R. Parker, "Fracture of Steels at Elevated Temperatures after Prolonged Loading," *Metals Technology*, Vol. 16 (1939).

(ao) H. Esser and S. Eckhardt, "Versuche mit einem neuen Dauerstandprüfer über den Verlauf von Zeit-Dehnungs Schaulinien Verschielener Stähle," *Archiv. für das Eisenhuttenwesen*, Vol. 13, p. 209 (1939).

(ap) J. J. Kanter and E. A. Sticha, "Creep Rates from Tests of Short Duration," *Transactions*, Am. Soc. Metals, Vol. 28, p. 257 (1940).

(aq) A. Nadai and J. Boyd, "Relaxation of Steels at Elevated Temperatures, A New Automatic Relaxation Machine," *Proceedings* of the Fifth International Congress for Applied Mechanics, John Wiley & Sons, Inc., N. Y., 1939.

(ar) K. Lohberg and F. Wollbank, "Härte-Kriechversuche an Zinklegierungen," *Zeitschrift für Metallkunde*, Vol. 32, p. 419 (1940).

(as) M. Manjoine and A. Nadai, "High Speed Tension Tests at Elevated Temperatures," *Proceedings*, Am. Soc. Testing Mats., Vol. 40, p. 822 (1940).

(at) A. Pomp and A. Krisch, "The Creep Resistance of Test Pieces as Determined in the Air Furnace by Different Methods," *Metallurgia*, March, 1940, p. 165.

(au) H. J. Tapsell and L. E. Prosser, "The Creep Properties of a 0.31 per cent Carbon, 0.64 per cent Molybdenum Cast Steel" *Proceedings*, Inst. of Mechanical Engrs., Vol. 144, p. 91 (1941).

(av) A. Nadai and M. Manjoine, "High-Speed Tension Tests at Elevated Temperatures," Parts II and III, *Journal of Applied Mechanics*, Vol. 8, p. A-77 (1941).

(aw) W. E. Trumpler, "Relaxation of Metals at High Temperatures," *Journal of Applied Physics*, Vol. 12, No. 3, March, 1941, pp. 248–253.

(ax) MacGregor and Welch, "True Stress-Strain Relations at High Temperatures by the Two-Load Method," *Metals Technology*, Vol. 9, p. TP-1507 (1942).

(ay) Saul Dushman, "Quick Method of Measuring Creep in Metals," Abstract of a paper delivered at a 1942 meeting of the American Society of Rheology, *Automobile Engineer*, 1942.

(az) Erich Fetz, "Dynamic Hardness Testing of Metals and Alloys at Elevated Temperatures," *Transactions*, Am. Soc. Metals, Vol. 30, December, 1942.

(aaa) H. E. Strauss, "Time-to-Fracture Tests on Platinum, 10 per cent Iridium-Platinum and 10 per cent Rhodium-Platinum Alloys," *Metals Technology*, Vol. 10, p. TP-1562 (1943).

DISCUSSION

Mr. Ernest L. Robinson.[1]—This report represents a valuable comparison between a large number of different ways of running tests at high temperature. It is illuminating to have such a complete comparison for low-carbon and carbon-molybdenum steel.

However, certain suppositions which the report takes for granted are provocative of comment. The fact that all the various tests are referred to the 1000-hr. constant stress creep test implies that there is some particular virtue in that special test. In order to make this appear as a "long-time test" certain other tests such as the long-time rupture test and the "flow rate" type of relaxation test (both of which are normally several or many times as long as the 1000-hr. creep test) are interpreted as short-time tests by using only the first few hours of results. If this is not a misuse of the data, it is at least a misuse of the name.

It would be quite appropriate to point out the shortcomings of the 1000-hr. creep test to give proper evaluations of long-time rupture strength or relaxation strength. Instead, the report implies that all the tests listed are attempts to dodge long-time testing; whereas, this is most certainly not the case in a number of these tests. They are tests to evaluate properties not revealed or, at best, only qualitatively indicated by the 1000-hr. creep test. Among these tests which are useful on their own account are the short-time tension test, the long-time constant stress rupture test, and the long-time constant stress and constant strain tests. The latter is called the relaxation test, and it yields information on suitability for bolting service.

It would be a valuable job for further investigation to correlate the 1000-hr. creep test with the longer time properties indicated by the other tests, and see to what extent it is useful in indicating the desired characteristics. The shortcomings of the 1000-hr. creep test have been discussed elsewhere.

Mr. J. S. Worth.[2]—Mr. Robinson feels the report "implies that there is some particular virtue" in the 1000-hr. constant stress creep test. The creep test does have the virtue of determining a high-temperature property of metals on which most designers of high-temperature equipment base their working stresses. This is particularly true in the case of the steam power equipment industry where tables of maximum allowable working stresses have been derived mainly from available creep data in the range of temperatures where creep becomes important.

The shortcomings of the 1000-hr. creep test to which Mr. Robinson calls attention should certainly be recognized. This time period was chosen by Project No. 25 because in the past the majority of creep tests have not been longer. Often, however, it is necessary to prolong the test considerably in order to obtain a reasonably constant secondary creep rate, and today, lengthening the test seems to be the general trend.

It was not the intention of the Project to imply that every other test investigated is useful only as a short-time test. In fact, the following statement appears in the report:[3] "It should be recognized that some of the short-time tests listed above, including the step-down relaxation test and the constant-strain relaxation test, might be considered more or less long-time tests, as will be explained in the description of each short-time test method." Instead, it was hoped that the results obtained during the first few hours of such tests might show a definite relationship to the secondary period of the creep test and thus provide a rough estimate of creep characteristics.

As it would not have served either the primary or secondary objects of the project to attempt a correlation of various long-time tests with the creep test, it was necessary to disregard normal long-time results.

---

[1] Turbine Engineering Dept., General Electric Co., Schenectady, N. Y.

[2] Chairman of Project No. 25, Assistant Metallurgical Engineer, Bethlehem Steel Co., Inc., Bethlehem, Pa.

[3] See p. 187.

REPORT OF JOINT COMMITTEE
ON
FILLER METAL

The Joint A.W.S.-A.S.T.M. Committee on Filler Metal was organized and continues to function as the means of correlating the mutual interests of the American Welding Society and the American Society for Testing Materials in matters relating to standards for filler metal.

Subsequent to the 1943 Annual Meeting, the Joint Committee on Filler Metal presented to the Society through Committee E-10 on Standards a proposed revision of the Tentative Specifications for Iron and Steel Arc-Welding Electrodes (A 233 - 42 T). The revised specifications were accepted[1] by Committee E-10 on October 7, 1943, and assigned the designation A 233 - 43 T. They appear in the 1943 Supplement to Book of A.S.T.M. Standards, Part I.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Iron and Steel Arc-Welding Electrodes (J. H. Deppeler, chairman).—This subcommittee originally was composed of the membership of the entire main committee. On March 24, 1944, the Advisory Committee, voted by letter ballot to reconstitute the subcommittee and reduce its membership to manufacturers of electrodes and core wire, balanced by an equal number of members representing the consumer interests. The subcommittee as reconstituted is to consider further revisions in the Tentative Specifications for Iron and Steel Arc-Welding Electrodes (A 233 - 43 T) and it is expected that revised specifications will be submitted for approval later this year.

Subcommittee II on Iron and Steel Gas-Welding Rods (J. H. Critchett, chairman).—This subcommittee has been inactive during the past year, but it plans to resume its activity and review the Tentative Specifications for Iron and Steel Gas-Welding Rods (A 251 - 42 T) to determine if there is need for amplifying or revising them.

Subcommittee III on Aluminum and Aluminum-Alloy Filler Metal (G. O. Hoglund, chairman).—This subcommittee, which prepared the Tentative Specifications for Aluminum and Aluminum-Alloy Metal Arc Welding Electrodes (B 184 - 43 T) is planning to prepare specifications for aluminum and aluminum-alloy gas welding rods.

Subcommittee IV on High-Alloy Steel Filler Metal (R. D. Thomas, chairman).—A second draft of proposed tentative specifications for stainless-steel arc-welding electrodes has been prepared and referred to the members of the subcommittee for comment. These specifications will be considered at the June meeting of the subcommittee, being held in conjunction with the Annual Meeting of the Society, following which it is expected they will be submitted to the main committee.

---

[1] In submitting this recommendation to Committee E-10 on Standards, the A.W.S.-A.S.T.M. Joint Committee on Filler Metal reported results of the letter ballot vote as follows: Of a total membership of 68, 48 members returned their ballots, of whom 42 voted affirmatively, 1 negatively, and 5 members marked their ballots "not voting."

Subcommittee V on Nickel and Nickel-Alloy Filler Metal (O. B. J. Fraser, chairman).—During the past year a tentative draft of specifications for filler metal of nickel, monel, inconel, illium and the several Hastelloy compositions was prepared and discussed with the manufacturers of these compositions. Sufficient data were not available for illium and the Hastelloys and it appears that the initial specifications will have to be confined to the other materials mentioned. It is expected that a tentative draft of the specifications will be submitted shortly for consideration by the subcommittee following which approval of the specifications will be requested.

Subcommittee VI on Copper and Copper Alloy Filler Metal (C. E. Swift, chairman).—This subcommittee is in its first year of operation and is engaged in the preparation of specifications for copper and copper-alloy electrodes, which it is expected will be available in the near future.

Subcommittee VII on Electrode Chart (J. H. Humberstone, chairman).—This subcommittee has been organized to prepare a chart showing the various trade names and manufacturers of electrodes under each of the classifications of the Tentative Specifications for Iron and Steel Arc-Welding Electrodes (A 233 – 43 T). Consideration will also be given to the preparation of a similar chart for gas-welding rods.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, J. H. Deppeler.
Vice-Chairman, O. B. J. Fraser.
Vice-Chairman, J. H. Humberstone.
Secretary, S. A. Greenberg.

This report has been submitted to letter ballot of the committee which consists of 70 members; 50 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

J. H. DEPPELER,
Chairman.

L. M. DALCHER,
Secretary.
S. A. GREENBERG,
Acting Secretary.

REPORT OF COMMITTEE B-1

ON

COPPER AND COPPER ALLOY WIRES FOR ELECTRICAL CONDUCTORS

Committee B-1 on Copper and Copper-Alloy Wires for Electrical Conductors held no meetings during the year, prior to a meeting on June 28, 1944, but has carried on constructively through correspondence the work reported herein.

The committee now consists of 46 members, of whom 21 are classified as producers, 16 as consumers, and 9 as general interest members.

The present officers of Committee B-1 have been re-elected for the ensuing term of two years. In addition, E. H. Kendall has been elected Acting Secretary pending return of the secretary, Lt. Col. H. H. Stout, Jr., from service overseas.

I. New Tentative Standard

The committee recommends that the Emergency Specifications for Lead-Coated and Lead-Alloy-Coated Copper Wire for Electrical Purposes (ES – 1a)[1] be accepted for publication as tentative, with the following changes: (*1*) elimination of reference to hard-drawn wires, and deletion of provisions relating thereto; (*2*) addition of the word "soft" in the title and scope; and (*3*) changes in the numerical values of requirements for resistivity to those prescribed in the Standard Specifications for Tinned Soft or Annealed Copper Wire for Electrical Purposes (B 33 – 39).

This recommendation has been submitted to letter ballot of the committee which consists of 46 members; 39 members returned their ballots of whom 32 have voted affirmatively, 0 negatively, and 7 members marked their ballots "not voting."

II. Revision of Standard, Immediate Adoption

The committee recommends for immediate adoption revisions in the Standard Specifications for Concentric-Lay-Stranded Copper Conductors, Hard, Medium-Hard, or Soft (B 8 – 41),[2] as set forth below, and accordingly asks for a nine-tenths affirmative vote at the Annual Meeting in order that these modifications may be referred to letter ballot of the Society.

Section 1 (*a*).—Change to read as follows by the addition of the italicized words:

> 1. (*a*) These specifications cover concentric-lay-stranded conductors made from round copper wires, either uncoated or coated with tin, *lead, or lead-alloy,* for general use for electrical purposes.

Section 2.—Change Paragraph (*a*) to read as follows by the addition of the italicized words:

> 2. (*a*) The purchaser shall designate the type of wire *and the kind of coating, if any,* to be used in the conductor.

At the end of Paragraph (*b*), add to the list of approved specifications for copper wire which may be used in the manufacture of these stranded conductors a reference to the new Tentative Specifications for Lead-Coated and Lead-Alloy-Coated Soft Copper Wire for Electrical Purposes, referred to above.

---

[1] 1942 Book of A.S.T.M. Standards, Part I, p. 943.

[2] *Ibid.*, p. 712.

Section 6.—Change the first sentence of Paragraph (*a*) to read as follows by the addition of the italicized words:

> Tests for the physical and electrical properties of wires composing conductors made from annealed copper wire or from tinned, *lead-coated or lead-alloy-coated* soft copper wire may be made before stranding or on wires removed from the conductor.

Change Paragraph (*b*) to read as follows by the addition of the italicized words:

> (*b*) If a tinning, *lead-coating, or lead-alloy-coating* test is required, it shall be made on the wires prior to stranding.

These additions, which make these specifications applicable to lead or lead-alloy coated wires when desired, make obsolete the present Emergency Alternate Provisions EA - B 8 covering these materials and steps are accordingly being taken to have these alternate provisions withdrawn.[3]

This recommendation has been submitted to letter ballot of the committee which consists of 46 members; 38 members returned their ballots, of whom 33 have voted affirmatively, 0 negatively, and 5 members marked their ballots "not voting."

The committee is also planning to submit to the Standards Committee a proposed Tentative Method of Test for Resistivity of Copper and Copper Alloy Electrical Conductors[3] which is applicable to strip, rods, bars, tubes, and shapes.

A proposed method for determining the resistivity of copper and copper-alloy wires for electrical conductors will also be prepared.

A subject group is being appointed to prepare recommendations for consideration by the committee relative to values for the lengths of lay for inclusion in Table II of the Tentative Specifications for Bunch-Stranded Copper Conductors for Electrical Conductors (B 174 - 42T).

A subject group is also being appointed to study and report to the committee desirable modifications in the specifications for stranded conductors to provide for necessary overages in area to allow for subsequent processing or for particular purchaser's requirements.

This report has been submitted to letter ballot of the committee which consists of 46 members; 38 members returned their ballots, of whom 36 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the committee,

J. H. FOOTE,
Chairman.

E. H. KENDALL,
Acting Secretary.

---

[3] See Editorial Note, below.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee B-1 presented to the Society through Committee E-10 on Standards the proposed Tentative Method of Test for Resistivity of Copper and Copper Alloy Electrical Conductors referred to in the report. This recommendation was accepted by Committee E-10 on August 28, 1944, and the new tentative method will appear in the 1944 Book of A.S.T.M. Standards, Part I, p. 1545, under the designation B 193 - 44 T.

On the same date, the Standards Committee approved the withdrawal of the Emergency Specifications for Lead-Coated and Lead-Alloy-Coated Copper Wire for Electrical Purposes (ES - 1a) and Emergency Alternate Provision EA - B 8 in line with the actions set forth in this report.

REPORT OF COMMITTEE B-2

ON

NON-FERROUS METALS AND ALLOYS

Committee B-2 on Non-Ferrous Metals and Alloys held one meeting during the past year, on June 30, 1943, in Pittsburgh, Pa., during the 1943 Annual Meeting of the Society.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Refined Copper (J. L. Christie, chairman) has reviewed the embrittlement test requirements in the Tentative Specifications for Oxygen-Free Electrolytic Copper Wire Bars, Billets, and Cakes (B 170 – 43 T) and recommends that the following proposed revision in these tentative specifications be submitted to Committee E-10 on Standards:[1]

Section 6 (a).—Change to read as follows by the addition of the italicized words and figures: "6. (*a*) Test specimens, prepared from samples forged or hot-rolled and cold-drawn into wire of No. 6 B. & S. gage (0.162 in.) to No. 12 B. & S. gage (0.080 in.), shall be annealed in an atmosphere of hydrogen for 20 min. at 800 *to 875* C. (1472 *to 1607* F.) and shall withstand the bend test specified in Paragraph (*b*)."

This modification reconciles the specifications with those promulgated by Committee B-5 on Copper and Copper Alloys, Cast and Wrought.

Consideration was given to the publication of the Emergency Specifications for Fire-Refined Copper for Wrought Products and Alloys (ES – 7) as tentative. The subcommittee, after conferring with members of Committee B-5, recommends that the specifications be continued as an emergency standard; and has appointed a subgroup to draw up tentative specifications to cover the type of copper in question.

At the suggestion of Division B of Committee E-3 on Chemical Analysis of Metals, an editorial change is being made in the Standard Specifications for Fire Refined Copper Other than Lake (B 72 – 33). The number of decimal places to which the chemical composition is given is being changed by deleting from the minimum for copper the last two zeros after the decimal point, and from the maximum for each of the impurities listed, the last zero after the decimal point. It is believed that these editorial changes are in line with analytical precision.

On the recommendation of the Coordinating Committee on Non-Ferrous Metals and Alloys, the subcommittee is accepting sponsorship for the various coppers containing small amounts of added elements such as arsenic, phosphorus, and silver.

Subcommittee II on Refined Lead, Tin, Antimony, and Bismuth (T. A. Wright, chairman) has been inactive. The subcommittee has been requested, however, to reconsider the advisability of drawing up specifications for antimony and for tin.

Subcommittee III on White Metal Alloys (G. H. Clamer, chairman) recommended editorial changes in the Appendix of the Tentative Specifications for Soft Solder Metal (B 32 – 40 T), including the addition of three nominal compositions, and that the specifications be continued as tentative.

---

[1] See Editorial Note, p. 221.

A subgroup has been appointed to review Emergency Alternate Provisions EA – B 23a in the Standard Specifications for White Metal Bearing Alloys (Known Commercially as "Babbitt Metal") (B 23 – 26) and Emergency Alternate Provisions EA – B 32a in the Tentative Specifications for Soft Solder Metal (B 32 – 40 T) and to make recommendations regarding additions to and deletions from the alloys listed in line with W.P.B. tin order M–43. These revisions will be presented to Committee E-10[1] subsequent to the Annual Meeting.

Subcommittee IV on Refined Zinc and Wrought Zinc (E. H. Bunce, chairman), at the request of Committee B-6 on Die-Cast Metals and Alloys, has considered certain reductions in impurity content of the special high grade slab zinc in the Standard Specifications for Slab Zinc (Spelter) (B 6 – 37) and is submitting the suggested changes to letter ballot.

Subcommittee V on Precious Metals and Alloys (R. H. Leach, chairman) has had no assignments.

Subcommittee VI on Coated Metals is without a chairman. W. G. Schneider, having changed his employment, has resigned. Arrangements are being made for the election of a new chairman.

Subcommittee VII on Refined Nickel and High Nickel Alloys, Cast and Wrought (O. B. J. Fraser, temporary chairman) has not met during the past year. This subcommittee is currently reviewing the various standards under its jurisdiction prior to the printing of the 1944 Book of A.S.T.M. Standards.

The election of officers for the ensuing term of two years has resulted in the selection of the following:

Honorary Chairman, G. H. Clamer.
Chairman, E. E. Thum.
Vice-Chairman, R. H. Leach.
Secretary, G. Howard LeFevre.

This report has been submitted to letter ballot of the committee which consists of 117 members; 72 members returned their ballots, of whom 68 have voted affirmatively, and 1 negatively.

Respectfully submitted on behalf of the committee,

J. L. CHRISTIE,
Acting Chairman.

C. E. SWARTZ,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting Committee B-2 presented to the Society through Committee E-10 on Standards proposed revisions in the Tentative Specifications for Oxygen-Free Electrolytic Copper Wire Bars, Billets, and Cakes (B 170 – 43 T). This recommendation was accepted by the Standards Committee on September 21, 1944, and the revised tentative specifications appear in the 1944 Book of A.S.T.M. Standards, Part I, p. 1522, under the designation B 170 – 44 T.

On October 24, 1944, the Standards Committee accepted revisions in Emergency Alternate Provisions EA – B 23a applying to the Standard Specifications for White Metal Bearing Alloys (Known Commercially as "Babbitt Metal") (B 23 – 26) and in Emergency Alternate Provisions EA – B 32a applying to the Tentative Specifications for Soft Solder Metal (B 32 – 40 T), as recommended by Committee B-2. The revised emergency alternate provisions appear in the 1944 Book of A.S.T.M. Standards, Part I, under the designations EA – B 23b and EA – B 32b, respectively.

REPORT OF COMMITTEE B-3

ON

CORROSION OF NON-FERROUS METALS AND ALLOYS

Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys held a meeting in Pittsburgh, Pa., on June 29, 1943, and in Cincinnati, Ohio, on February 29, 1944.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, H. S. Rawdon.
Vice-Chairman, R. W. Waring.
Secretary, A. W. Tracy.

The committee consists of 84 members, of whom 66 are voting members; 32 are classified as producers, 22 as consumers, and 12 as general interest members.

I. New Tentative Standard

The committee recommends for publication as tentative a Method of Alternate Immersion Testing of Non-Ferrous Metals.[1]

This recommendation has been submitted to letter ballot of the committee which consists of 66 voting members; 55 members returned their ballots, of whom 44 have voted affirmatively, 1 negatively, and 10 members marked their ballots "not voting."

II. Revision of Tentative Standard

The committee recommends an extensive revision of the Tentative Method of Salt Spray Testing of Non-Ferrous Metals (B 117 – 41 T).[1]

This recommendation has been submitted to letter ballot of the committee which consists of 66 voting members; 54 members returned their ballots, of whom 42 have voted affirmatively, 1 negatively, and 11 members marked their ballots "not voting."

Activities of Subcommittees

Subcommittee I on Total Immersion Test (A. W. Tracy, chairman).—A working group has been appointed to study the applicability of the Recommended Practice for Conducting Plant Corrosion Tests (A 224 – 41) to the corrosion of non-ferrous metals, and to suggest any revisions necessary for its approval for use in this field.

Subcommittee II on Alternate Immersion Test (H. W. Schmidt, chairman).—The subcommittee has prepared a detailed description of the alternate immersion test method to conform with that of the Tentative Method of Total Immersion Testing of Non-Ferrous Metals (B 185 – 43 T) which is being submitted herewith for publication as tentative.

Subcommittee III on Spray Test (C. E. Heussner, chairman).—At its meeting in Cincinnati, members of this subcommittee agreed that considerable work needed to be done on standardization of the details of the Tentative Method of Salt Spray Testing of Non-Ferrous Metals (B 117 – 41 T) to make it acceptable to all interested parties.

On March 15, 1944, a special meeting was held at the National Bureau of Standards which was attended by representatives of several Government agencies and A.S.T.M. committees interested in the salt spray test. A method was drafted at this meeting from which it appears that a satisfactory salt spray test procedure agreeable to the A.S.T.M. and all interested agencies may be formulated. The revised method is now ready for publication in the 1944 Book of A.S.T.M. Standards.

---

[1] This method was accepted as tentative by the Society and appears in the 1944 Book of A.S.T.M. Standards, Part I.

Subcommittee VI on Atmospheric Corrosion (W. H. Finkeldey, chairman).—A report on the results of tests on specimens cut from plates exposed to the atmosphere for ten years has been prepared by the subcommittee and is appended hereto.

Subcommittee VII on Weather (F. L. LaQue, chairman).—This subcommittee has confined its activities to correspondence with the Research Committee on Climatology of the American Geophysical Committee working towards cooperation at some more appropriate time in measuring those weather factors that are important in atmospheric corrosion.

Subcommittee VIII on Galvanic and Electrolytic Corrosion (L. J. Gorman, chairman).—The galvanic couples on exposure at Kure Beach, Wilmington, N. C., were inspected and the contact resistance checked in November, 1943. The couples on exposure at New York, N. Y., were inspected and the contact resistance checked in February, 1944. The contact resistance in all of the couples at Kure Beach was low except as follows:

1. The mild-steel couples still on exposure are open-circuited, as reported in the previous inspection.
2. Some of the 24ST aluminum couples have developed high-contact resistance. Resistances as high as 3000 ohms were measured on some of these couples.

The contact resistance of the couples exposed at New York was low in all cases, including the mild-steel couples still on exposure.

Aside from that mentioned above, there was no apparent change in the appearance or condition of the couples over that reported in the previous inspection. It is planned to inspect the couples at State College, Pa., and Altoona, Pa., during the summer.

As mentioned in the previous report, it is planned to obtain new specimens of mild steel in which the copper content is higher than that of the mild steel initially used. The copper in the first mild steel specimen amounted to 0.018 per cent. The new specimen will have a copper content of 0.05 to 0.08 per cent. The stainless steel disks for the new couples are being machined by the Union Carbon and Carbide Co. The mild steel for these couples has not been delivered at this time. Additional material has been received for the 24ST aluminum specimens.

The A.S.T.M. test racks at La Jolla, Calif., are being repaired and will soon be ready to receive specimens. The galvanic couples for exposure, with exception of the mild steel, are on hand and will be shipped to La Jolla as soon as the racks are ready and as soon as the mild-steel specimens have been received and assembled.

Subcommittee VIII in conjunction with Subcommittee IV of A.S.T.M. Committee B-7 on Light Metals and Alloys, Cast and Wrought, has under consideration a program for testing magnesium and magnesium alloys in couple combination with other metals. Arrangements have been made with Subcommittee IV of Committee B-7 to prepare a tentative program which will be submitted to Subcommittee VIII for consideration. A subgroup of Subcommittee VIII, including representation from Subcommittee IV, will be appointed to work out the details of this program.

This report has been submitted to letter ballot of the committee which consists of 66 voting members; 61 members returned their ballots, of whom 58 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the committee,

SAM TOUR,
Chairman.

A. W. TRACY,
Secretary.

REPORT OF SUBCOMMITTEE VI ON ATMOSPHERIC CORROSION TESTS OF NON-FERROUS METALS AND ALLOYS

This report is a continuation of the 1943[1] report of Subcommittee VI in which was presented the data gathered from the tension tests and weight loss determinations made on specimens removed after approximately ten years' exposure to the atmosphere at the various test locations. Detailed information concerning the testing procedures used, summary of meteorological data for the 10-yr. period, and visual appearance of the corroded metals and alloys, etc., was given in the 1943 report. The tension test results on specimens cut from the corroded and chemically cleaned 9 by 12-in. plates, not completed in time for inclusion in the 1943 report are given in this year's report. Also included are such conclusions as the committee believes can be drawn at this time.

COMPILATIONS OF REFERENCE DATA

Since the end of the 10-yr. exposure period roughly marks a halfway point in the investigation, as originally planned by the committee, it is considered advisable to include in this year's report compilations of certain test data and the results of various calculations based upon them (Tables VI to XII, inclusive) in order that this information might be readily available in a series of tables instead of being scattered throughout several reports. No tabulation of weight loss data for Rochester is included in this report since at this location the rack was dismantled and the test specimens destroyed in 1942. For the sake of completeness, certain data already published in the 1943 report have been included in these tabulations. Data covering tests of materials removed from the racks after exposure periods shorter than ten years have had to be omitted because of space limitations. However, a study of the trend of corrosion in any one of the metals or alloys included in these tests may be made by referring to the tables of test data included in the committee's previously published reports[2] covering the 1-yr., 3-yr., and 6-yr. exposure periods. A complete description of all the metals and alloys, included in this investigation, and information with regard to their physical properties, chemical composition, process of manufacture, rolling treatment, and metallographic structure appeared in the 1932 report of the subcommittee.[3]

LOSS IN WEIGHT DATA

Loss in weight data obtained by weighing the chemically cleaned 9 by 12-in. plates after approximately ten years' exposure in the various atmospheres was given in the 1943 report as the total loss in grams for each plate. These data, together with various calculations based thereon, are again included in this year's report, and appear in Tables VI to XII, inclusive.

The total loss in weight in grams for each plate over the 10-yr. period has been converted into ounces per square foot using the following formula:

$$\text{loss in weight, oz. per sq. ft.} = \frac{\text{avg. wt. change, g.}}{42.8}$$

---

[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 43, p. 137 (1943)

[2] *Proceedings*, Am. Soc. Testing Mats., Vol. 33, Part I, p. 234 (1933); Vol. 35, Part I, p. 142 (1935); and Vol. 38, Part I, p. 194 (1938).

[3] *Proceedings*, Am. Soc. Testing Mats., Vol. 32, Part I, p. 201 (1932).

Similarly, the loss in grams per plate has been converted to milligrams per square centimeter for the 10-yr. exposure period using the formula:

$$\text{loss in weight, mg. per sq. cm.} = \frac{\text{avg. wt. change, mg.}}{1403}$$

The average penetration in inches for the 10-yr. exposure period has been calculated from the formula:

$$\text{average penetration, in.} = \frac{0.393 \times \text{avg. loss in wt., g. per sq. cm.}}{\text{density, g. per cu. cm.}}$$

The density figures used in making these calculations were the same as those published in the subcommittee's report for 1933.[4]

Each of the foregoing calculations was made on the losses for each of the two plates representing a given metal or alloy, and the average of these individual results is reported in the tables.

TENSION TESTS ON SPECIMENS CUT FROM CORRODED AND CHEMICALLY CLEANED 9 BY 12-IN. PLATES

Drop in tensile strength has been used by the committee, from the start of this investigation, as a measure of corrosion. In reviewing results of tests made on specimens after 1, 3, and 6 yr. exposure, the question has often been raised as to what effect corrosion taking place at the edges of the test section (notch effect) might have on the tension data obtained from such specimens. An attempt has been made to develop some information on this point by making tension tests on specimens cut from the corroded and chemically cleaned 9 by 12-in. plates, since such specimens have freshly machined edges from which any notch effects due to corrosion are absent.

The procedure followed in obtaining from the corroded plates after approximately ten years' exposure sixteen tension test specimens of each material was described in detail in the 1943 report. Results of the tension tests made on these specimens are reported in Tables VI to XII as average tensile strengths. These results are recorded in two ways. In one case, the tensile strength in pounds per square inch was determined from the breaking load using a cross-sectional area of the test specimen calculated from the actual thickness and width of the test section, determined by micrometer caliper measurements, and the results of the sixteen individual tests were averaged. In the second case, the ultimate tensile strength was calculated from the average breaking load on the basis of a test section area found by multiplying the actual average width of the test section, as measured by micrometer calipers on the sixteen specimens, by the original thickness of the 9 by 12-in. plates before they were exposed to the atmosphere. This original thickness was determined by averaging the thickness of the individual tension specimens used in determining the original or initial tension test values for all materials. Since in every instance except one (material F) all the specimens, both for tension testing and the 9 by 12-in. plates, were cut from one strip of rolled metal, it may be assumed that the average thickness of any group of tension specimens cut from this rolled strip would probably represent, with reasonable accuracy, the average thickness of all of the particular material, and therefore may be assumed to be the original thickness of the plates before they were exposed to corrosion in the atmosphere.

In the first instance mentioned above,

---

[4] *Proceedings*, Am. Soc. Testing Mats., Vol. 33, Part I, p. 234 (1933).

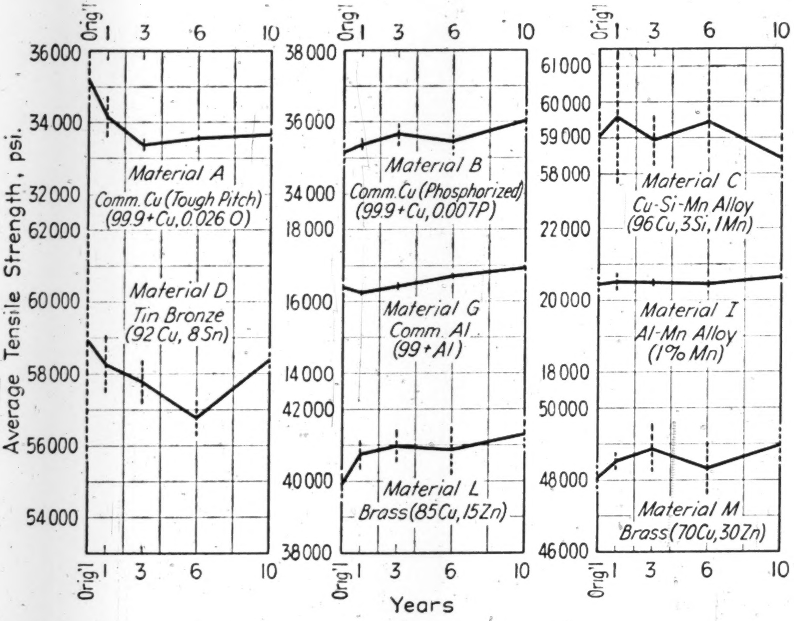


FIG. 1.—Tension Data of Storage Specimens.

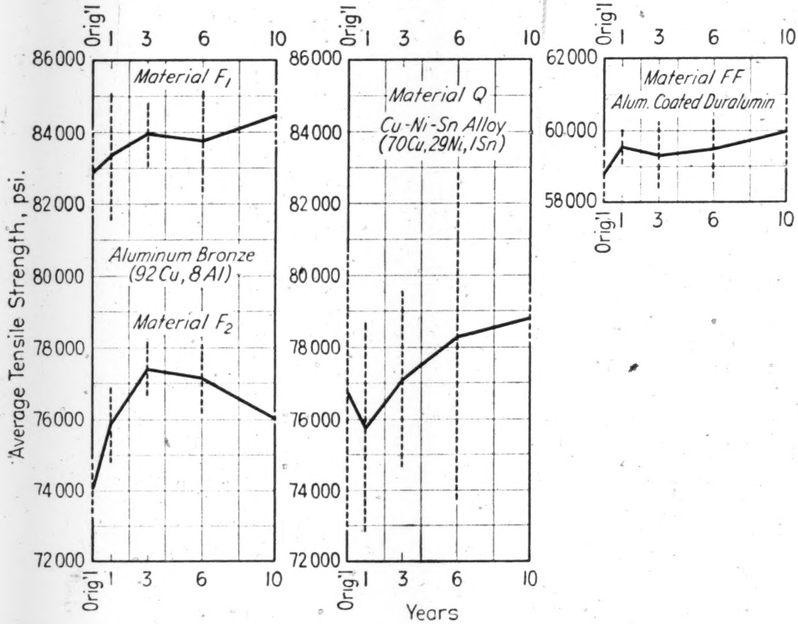


FIG. 2.—Tension Data of Storage Specimen.

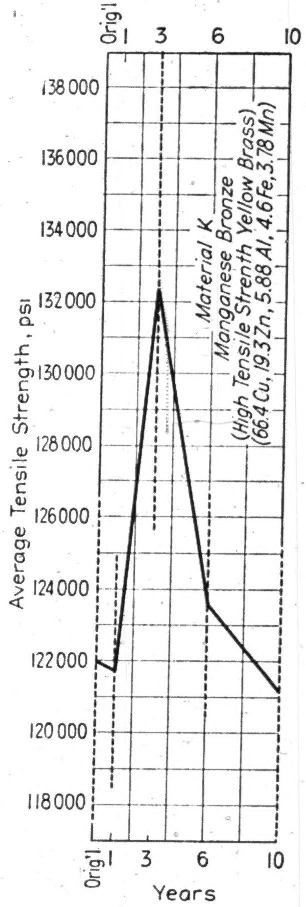


FIG. 3.—Tension Data of Storage Specimens.

the standard deviation was determined for each set of sixteen tension specimens representing a given material and is reported along with the average tensile strength in Tables VI to XII.

In the last column of Table I are given data on tension tests of specimens cut from spare 9 by 12-in. plates stored at the Bureau for 10 yr. These "storage" tension data were used in determining the percentage change in tensile strength (reported in Tables VI to XII) of the specimens cut from the exposed 9 by 12-in. plates. Both sets of plates were chemically cleaned before cutting out tension specimens.

CHANGES IN TENSILE STRENGTH OF STORAGE SPECIMENS

A study of the data obtained from tension tests of specimens exposed for 1-, 3-, 6-, and 10-yr. periods shows that in a number of cases, particularly where the amount of corrosion suffered is small, the specimens actually show increases in strength instead of decreases when compared with the initial tension tests made on the materials before they were exposed to the atmosphere. This possibility was anticipated by the committee when the tests were first planned,

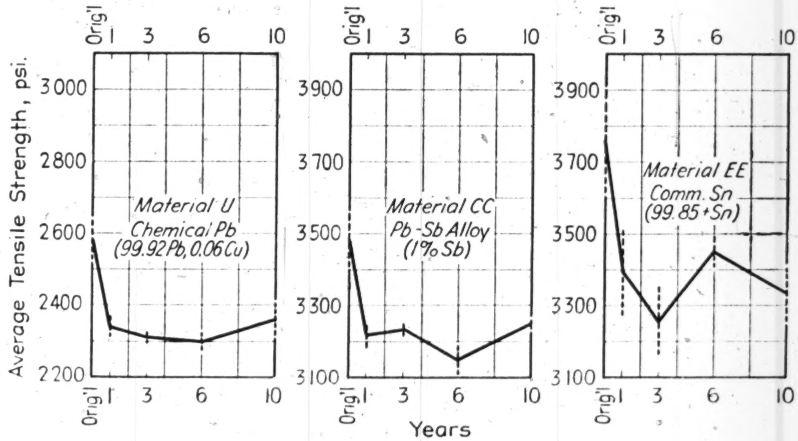


FIG. 4.—Tension Data of Storage Specimens.

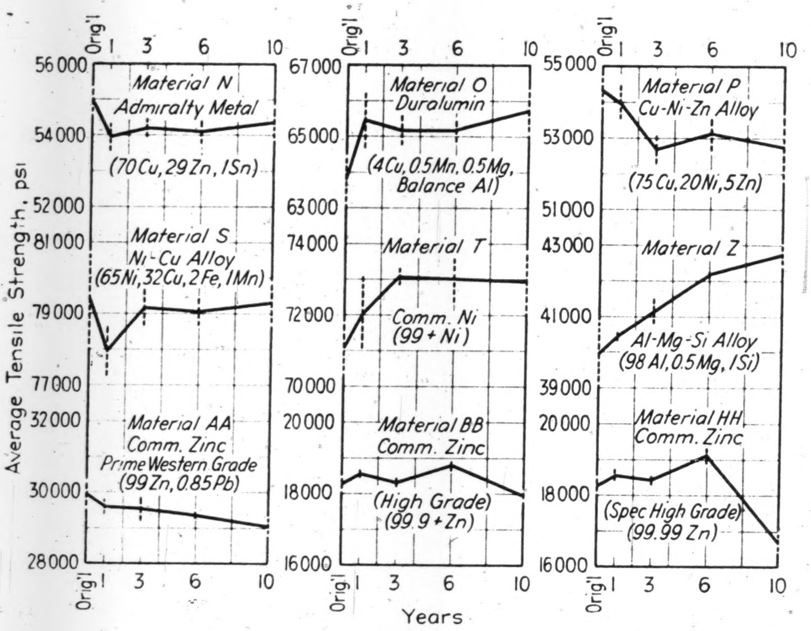


FIG. 5.—Tension Data of Storage Specimens.

TABLE I.—SUMMARY OF TENSION DATA OF STORAGE SPECIMENS.

Material	Original		After Storage									
			1 yr.		3 yr.		6 yr.		10 yr.		10 yr., Cut from 9 by 12-in. Plates	
	psi.	Std. Dev.	psi.	Std. Dev.	psi.	Std. Dev.	psi.	Std. Dev.	psi.	Std. Dev.	psi.	Std. Dev.
A	35 200	556.8	34 180	584.3	33 380	157.3	33 570	46.9	33 660	167.2	34 280	150.9
B	35 150	275.4	35 380	168.2	35 680	313.5	35 460	184.2	36 020	307.4	35 080	123.6
C	59 070	679.9	59 620	1836.0	58 950	665.2	59 480	884.2	58 490	626.3	62 880	292.0
D	58 930	300.1	58 280	786.4	57 770	584.7	56 780	488.3	58 380	212.4	54 840	629.5
F[a]	74 070	734.9	75 830	1033.0	77 400	731.4	77 130	969.8	76 030	52.2	—	—
F[b]	82 860	1133.0	83 320	1772.0	83 920	900.5	83 750	1443.0	84 430	756.8	85 860	855.1
G	16 410	68.7	16 220	40.2	16 410	112.4	16 700	53.2	16 920	75.5	17 190	55.3
I	20 450	243.8	20 510	226.0	20 490	102.5	20 440	87.3	20 640	62.9	20 710	116.5
K	122 000	4422.0	121 710	3241.0	132 370	6695.0	123 560	3114.0	121 130	3992.0	121 970	4223.0
L	39 900	335.5	40 750	393.8	40 980	472.6	40 870	672.3	41 300	413.3	41 160	477.4
M	48 080	351.2	48 520	226.0	48 880	662.1	48 320	721.3	48 970	467.5	52 510	388.7
N	54 960	318.0	53 920	401.3	54 200	258.2	54 100	305.5	54 350	423.3	55 090	198.3
O	63 760	617.9	65 430	780.8	65 170	420.6	65 150	285.8	65 710	542.5	66 380	277.9
P	54 330	357.2	54 000	479.6	52 680	389.5	53 100	447.2	52 710	872.8	54 040	387.1
Q	76 790	3803.0	75 750	2917.0	77 100	2433.0	78 300	4546.0	78 800	5724.2	67 680	155.0
S	79 390	1278.0	77 930	702.0	79 150	522.0	79 050	377.5	79 420	485.0	79 650	862.5
T	71 100	637.4	72 050	987.8	73 080	227.0	73 000	611.0	73 170	923.0	73 350	775.6
U	2 580	54.8	2 340	28.5	2 310	16.3	2 300	25.7	2 350	54.1	2 240	19.6
Z	39 980	835.8	40 450	143.5	41 160	342.0	42 170	83.3	42 720	273.0	42 840	482.6
AA	29 940	298.2	29 600	200.0	29 530	309.4	29 380	90.8	29 080	211.9	28 540	157.6
BB	18 280	148.0	18 580	69.6	18 330	125.2	18 800	152.7	17 970	73.7	17 520	63.4
CC	3 480	75.8	3 210	33.4	3 230	18.1	3 150	41.3	3 250	13.8	3 050	36.8
EE	3 760	143.4	3 390	117.5	3 260	92.8	3 450	45.1	3 330	77.2	3 630	47.5
FF	58 790	657.7	59 530	484.6	59 300	921.4	59 470	819.8	59 940	944.4	59 200	2492.0
HH	18 280	167.7	18 570	159.5	18 430	134.8	19 120	205.2	16 690	245.8	19 150	317.8

---

[a] Original and storage set data for material F specimens exposed at Altoona, New York, Sandy Hook, Rochester, State College, and Key West.

[b] Original and storage set data for material F specimens exposed only at Phoenix and La Jolla.

TABLE II.—GRADED SUMMARY OF TOTAL LOSSES IN WEIGHT (IN GRAMS) AFTER APPROXIMATELY TEN YEARS EXPOSURE.

9 by 12-in. plates, chemically cleaned.

Position	Industrial or Semi-Industrial				Sea Coast						Rural			
	Altoona, Pa.		New York, N. Y.		Sandy Hook, N. J.		Key West, Fla.		La Jolla, Calif.		State College, Penna.		Phoenix, Ariz.	
	Exposed 3377 days, 9.25 yr.		Exposed 3426 days, 9.38 yr.		Exposed 3449 days, 9.45 yr.		Exposed 3402 days, 9.32 yr.		Exposed 3336 days, 9.14 yr.		Exposed 3386 days, 9.27 yr.		Exposed 3323 days, 9.10 yr.	
1	Z	−2.34	FF	−2.35	O	−0.16	FF	−0.13	T	−1.38	I	−0.09	G	−0.01
2	G	−2.36	Z	−2.70	G	−0.21	Z	−0.18	FF	−1.61	FF	−0.10	I	−0.01
3	FF	−2.60	G	−3.04	Z	−0.36	I	−0.33	F	−2.18	G	−0.12	FF	−0.01
4	O	−5.25	I	−3.92	I	−0.51	G	−0.35	I	−2.20	Z	−0.16	Z	−0.02
5	I	−5.92	O	−4.50	FF	−0.57	O	−0.64	S	−2.22	O	−0.21	O	−0.04
6	CC	−8.65	CC	−5.01	CC	—	T	−1.49	Z	−2.41	S	−1.47	T	−0.37
7	U	−10.82	U	−6.77	U	—	S	−1.92	G	−2.72	T	−1.95	S	−0.48
8	B	−14.38	EE	−12.25	EE	—	F	−3.60	Q	−3.37	F	−2.16	F	−0.69
9	A	−14.75	B	−14.49	S	−7.89	P	−3.69	M	−3.50	K	−3.59	Q	−0.95
10	EE	−15.65	A	−14.97	A	−8.24	HH	−3.84	P	−3.81	D	−4.11	P	−1.12
11	O	−16.27	S	−16.61	B	−8.53	N	−4.39	N	−4.69	P	−4.36	HH	−1.18
12	S	−17.30	C	−18.63	T	−9.35	M	−4.40	O	−5.71	Q	−4.36	N	−1.19
13	D	−18.13	F	−18.67	M	−11.97	Q	−4.43	U	−6.56	EE	−4.55	L	−1.25
14	F	−18.73	D	−22.55	P	−12.95	BB	−4.57	L	−7.38	M	−4.74	K	−1.29
15	N	−19.68	P	−22.67	N	−13.66	AA	−5.24	CC	−9.56	N	−4.80	M	−1.36
16	Q	−26.25	N	−23.10	C	−13.76	L	−5.81	HH	−12.25	CC	−5.23	B	−1.44
17	P	−26.79	Q	−25.16	Q	−13.77	A	−6.31	B	−13.96	C	−5.69	A	−1.71
18	L	−26.95	M	−26.35	HH	−13.85	B	−6.56	BB	−16.00	B	−6.61	BB	−1.79
19	M	−30.41	L	−27.41	AA	−14.10	CC	−8.28	A	−16.58	A	−7.23	D	−1.99
20	HH	−44.55	T	−40.56	BB	−14.25	U	−8.77	K	−17.21	U	−7.64	C	−2.14
21	T	−47.89	HH	−48.78	L	−14.68	D	−9.66	AA	−17.45	BB	−8.73	AA	−2.53
22	AA	−48.63	AA	−49.25	F	−15.08	C	−12.03	C	−22.74	HH	−9.11	EE	−3.32
23	BB	−49.31	BB	−51.61	D	−15.59	K	−15.66	EE	−23.51	L	−9.22	U	−3.84
24	K	−70.07	K	−59.23	K	−30.00	EE	−21.90	D	−25.61	AA	−10.70	CC	−4.39

NOTE.—Specimens at the Pittsburgh and Rochester locations missing—stolen or destroyed some time between 1937 and 1941

TABLE III.—GRADED SUMMARY OF AVERAGE PENETRATION (in. $\times 10^{-4}$) AFTER APPROXIMATELY TEN YEARS EXPOSURE.

Data calculated from average total loss in weights of the 9 by 12-in. plates given in Table II.

Position	Industrial or Semi-Industrial				Sea Coast						Rural			
	Altoona, Pa.		New York, N. Y.		Sandy Hook, N. J.		Key West, Fla.		La Jolla, Calif.		State College, Pa.		Phoenix, Ariz.	
	Exposed 3377 days, 9.25 yr.		Exposed 3426 days, 9.38 yr.		Exposed 3449 days, 9.45 yr.		Exposed 3402 days, 9.32 yr.		Exposed 3336 days, 9.14 yr.		Exposed 3386 days, 9.27 yr.		Exposed 3323 days, 9.10 yr.	
1	CC	2.14*	CC	1.24*	O	0.16	FF	0.13	T	0.43	I	0.09	I	0.01
2	Z	2.43	U	1.67*	G	0.21	Z	0.19	S	0.70	FF	0.10	G	0.01
3	G	2.44	FF	2.38	Z	0.37	I	0.34	F	0.78	G	0.12	Z	0.02
4	FF	2.64	Z	2.81	I	0.52	G	0.36	Q	1.06	Z	0.16	O	0.04
5	U	2.67*	G	3.15	FF	0.57	T	0.47	M	1.15	O	0.21	FF	0.10
6	B	4.51	I	4.02	CC	1.90[a]	S	0.61	P	1.21	S	0.46	T	0.12
7	A	4.64	O	4.52	U	2.00[a]	O	0.64	N	1.54	T	0.61	S	0.15
8	O	5.27	B	4.55	S	2.51	P	1.17	U	1.62*	F	0.77	F	0.24
9	C	5.34	A	4.71	A	2.58	F	1.29	FF	1.63	K	1.27*	Q	0.30
10	S	5.51	EE	4.71	B	2.67	Q	1.40	I	2.26†	CC	1.29*	P	0.35
11	D	5.76	S	5.30	T	2.96	N	1.44	L	2.36	D	1.31	N	0.39
12	EE	6.03	C	6.11	M	3.93	M	1.45	CC	2.36*	Q	1.37	L	0.40
13	I	6.07	F	6.71	P	4.10	HH	1.50	Z	2.51*	P	1.38	M	0.44
14	N	6.46	D	7.16	Q	4.35	BB	1.79	G	2.81*	M	1.55	B	0.45
15	F	6.73*	P	7.18	N	4.48	L	1.86	B	4.39	N	1.57	K	0.45
16	Q	8.30	N	7.58	C	4.51	A	1.98	HH	4.81	EE	1.75	HH	0.46
17	P	8.49	Q	7.96	L	4.70*	B	2.05	A	5.21	C	1.86	A	0.53
18	L	8.62*	M	8.66	D	4.96*	AA	2.05	O	5.73	U	1.88*	D	0.63
19	M	10.00	L	8.77*	F	5.43	CC	2.05*	K	6.10	B	2.07	C	0.70
20	T	15.15	T	12.81	HH	5.44	U	2.16*	BB	6.29	A	2.28	BB	0.70
21	HH	17.50	HH	19.13	AA	5.54	D	3.06	AA	6.85	L	3.01	U	0.94*
22	AA	19.10	AA	19.32	BB	5.59	C	3.94	C	7.46	BB	3.42	AA	0.99
23	BB	19.31	BB	20.21	EE	7.00[a]	K	5.56*	D	8.14	HH	3.57	CC	1.09*
24	K	24.88†	K	21.00†	K	10.61*	EE	8.41	EE	9.05	AA	4.20	EE	1.28

[a] Specimen lost—values appearing in table estimated.

NOTE.—Symbols indicate depth of pitting from actual measurements.
Where no symbols appear, pitting negligible—less than 0.001 in. deep.
* Pitting 0.001 to 0.003− in.
† Pitting 0.003+ to 0.012 in.

TABLE IV.—GRADED SUMMARY OF PERCENTAGE CHANGES IN TENSILE STRENGTHS AFTER APPROXIMATELY TEN YEARS EXPOSURE.

Samples exposed as machined tension specimens.

Position	Industrial or Semi-Industrial						Sea Coast						Rural			
	Altoona, Pa.		New York, N. Y.		Rochester, N. Y.		Sandy Hook, N. J.		Key West, Fla.		La Jolla, Calif.		State College, Pa.		Phoenix, Ariz.	
	Exposed 3695 days, 10.11 yr.		Exposed 3741 days, 10.24 yr.		Exposed 3694 days, 10.11 yr.		Exposed 3733 days, 10.22 yr.		Exposed 3693 days, 10.11 yr.		Exposed 3636 days, 9.95 yr.		Exposed 3687 days, 10.09 yr.		Exposed 3650 days, 10.00 yr.	
1.....	U	+0.9	U	+0.4	U	+0.9	HH	+0.3	HH	+5.0	U	+1.7	HH	+3.3	HH	+7.6
2.....	FF	−1.9	FF	−1.9	I	−0.1	U	−1.7	S	+0.6	S	+0.6	K	+2.1	Q	+2.6
3.....	S	−4.5	CC	−2.2	HH	−1.0	I	−3.0	FF	+0.6	T	−1.2	U	+1.3	U	+2.6
4.....	CC	−5.2	S	−5.4	S	−1.6	G	−3.1	U	0	F	−1.4	S	+0.2	Z	+1.7
5.....	B	−5.9	A	−6.2	C	−2.2	T	−3.1	I	−0.5	HH	−1.7	G	+0.1	I	+0.9
6.....	A	−6.8	I	−6.2	G	−2.7	A	−3.4	T	−0.6	P	−2.0	I	−0.3	L	−0.2
7.....	G	−7.0	B	−6.3	CC	−3.7	B	−3.5	L	−1.4	FF	−2.0	FF	−0.6	M	−0.2
8.....	D	−7.2	G	−6.3	D	−4.1	S	−3.5	B	−1.5	N	−2.5	T	−0.8	O	−0.2
9.....	F	−7.5	P	−7.3	A	−4.6	CC	−3.7	G	−1.7	Q	−3.0	O	−1.0	P	−0.4
10.....	C	−7.7	L	−7.6	P	−4.6	P	−4.3	A	−1.8	L	−3.5	Q	−1.5	S	−0.4
11.....	P	−8.7	C	−7.9	FF	−4.9	L	−4.6	N	−1.9	C	−5.1	P	−1.6	B	−0.5
12.....	N	−9.0	N	−7.9	B	−5.1	FF	−4.6	P	−1.9	D	−5.7	Z	−1.8	D	−0.6
13.....	L	−9.9	D	−8.0	N	−5.4	D	−5.0	AA	−1.9	CC	−6.2	N	−2.2	N	−0.6
14.....	I	−10.4	Q	−8.8	L	−5.8	F	−5.2	M	−2.0	B	−7.6	F	−2.4	A	−0.8
15.....	Q	−11.4	F	−9.7	F	−6.8	N	−5.2	BB	−2.8	I	−7.6	C	−2.5	FF	−1.1
16.....	T	−15.0	EE	−12.0	Z	−7.0	C	−5.3	C	−2.9	M	−8.0	B	−3.1	BB	−1.4
17.....	Z	−15.3	HH	−12.1	M	−7.1	AA	−6.7	F	−3.2	A	−10.0	D	−3.1	C	−1.6
18.....	O	−15.8	Z	−12.2	O	−7.3	BB	−6.8	Q	−3.6	BB	−10.5	CC	−3.1	F	−1.7
19.....	EE	−15.9	T	−13.4	Q	−7.4	Q	−7.4	Z	−3.7	AA	−10.9	M	−3.2	G	−1.7
20.....	A	−22.2	O	−14.1	BB	−7.6	Z	−9.1	D	−3.8	G	−14.1	L	−3.7	AA	−1.9
21.....	BB	−22.8	AA	−20.7	AA	−7.8	O	−11.0	O	−5.2	K	−23.4	A	−4.2	T	−2.0
22.....	HH	−22.8	BB	−20.9	T	−8.6	M	−12.0	CC	−5.8	Z	−27.1	BB	−4.7	K	−3.3
23.....	M	−30.9	M	−28.2	EE	−12.9	EE	−18.6	K	−13.3	EE	−27.6	AA	−6.0	CC	−6.5
24.....	K	−53.8	K	−53.3	K	−31.0	K	−19.4	EE	−16.5	O	−50.5	EE	−8.7	EE	−12.3

NOTE.—Pittsburgh specimens missing.

TABLE V.—GRADED SUMMARY OF PERCENTAGE CHANGES IN TENSILE STRENGTHS OF TENSION SPECIMENS CUT FROM CORRODED 9 BY 12-IN. PLATES AFTER CHEMICAL CLEANING.

Ultimate tensile strength calculated on basis of original area of specimen.

Position	Industrial or Semi-Industrial				Sea Coast						Rural			
	Altoona, Pa.		New York, N. Y.		Sandy Hook, N. J.		Key West, Fla.		La Jolla, Calif.		State College, Pa.		Phoenix, Ariz.	
	Exposed 3377 days, 9.25 yr.		Exposed 3426 days, 9.38 yr.		Exposed 3449 days, 9.45 yr.		Exposed 3402 days, 9.32 yr.		Exposed 3336 days, 9.14 yr.		Exposed 3386 days, 9.27 yr.		Exposed 3323 days, 9.10 yr.	
1.......	D	+3.8	F	+11.2	AA	+3.7	Z	+6.2	Q	+3.9	AA	+4.8	AA	+7.4
2.......	C	+1.2	D	+3.1	Q	+3.2	S	+4.7	S	+3.4	Q	+3.8	D	+4.7
3.......	Q	+1.2	FF	+1.8	C	+2.1	Q	+4.1	T	+2.8	C	+3.7	Z	+4.6
4.......	FF	+0.1	S	+1.2	Z	+2.1	AA	+4.0	AA	+2.4	T	+2.6	C	+4.5
5.......	S	−0.7	C	+0.9	FF	+1.9	BB	+3.0	D	+2.0	Z	+2.0	Q	+4.2
6.......	N	−2.2	Q	0	A	+1.1	C	+2.9	FF	+1.9	BB	+1.4	T	+3.5
7.......	U	−2.2	A	−0.7	BB	+1.1	D	+2.9	N	+1.5	N	+1.3	A	+2.0
8.......	B	−2.5	T	−0.7	F	+0.2	T	+2.8	C	+1.4	P	+1.2	FF	+2.0
9.......	T	−2.5	U	−0.9	I	−0.1	FF	+2.5	BB	+1.4	FF	+1.0	N	+1.7
10.......	P	−3.1	B	−1.1	P	−0.7	A	+1.0	B	−0.7	A	+0.6	BB	+1.7
11.......	G	−5.2	N	−1.9	N	−0.9	N	+0.8	P	−1.3	S	+0.6	S	+1.4
12.......	A	−5.3	P	−2.3	D	−1.1	I	+0.3	M	−1.7	M	−0.2	B	+1.3
13.......	L	−5.3	CC	−3.9	S	−1.5	B	−0.1	U	−1.8	B	−0.9	I	+0.1
14.......	O	−5.8	I	−4.0	B	−1.7	O	−0.3	L	−2.3	D	−0.9	M	−0.1
15.......	I	−5.9	L	−5.7	T	−1.7	G	−1.3	I	−2.7	I	−0.9	L	−0.5
16.......	BB	−6.9	Z	−6.0	G	−3.0	M	−1.3	A	−5.1	L	−2.8	O	−0.9
17.......	CC	−6.9	BB	−6.6	L	−3.1	U	−1.3	G	−5.3	G	−3.9	G	−1.4
18.......	Z	−8.5	G	−6.9	O	−3.4	P	−2.7	F	−6.6	O	−4.0	P	−1.6
19.......	AA	−8.7	EE	−8.5	M	−5.1	L	−2.9	CC	−7.2	EE	−5.0	U	−2.2
20.......	M	−14.0	AA	−8.9	HH	−11.5	K	−3.6	K	−9.9	CC	−5.6	K	−2.5
21.......	F	−14.8	M	−9.0	K	−18.3	HH	−9.2	HH	−9.9	U	−6.3	F	−4.9
22.......	HH	−18.4	O	−9.4	EE	—[a]	CC	−10.2	EE	−12.9	F	−9.7	HH	−7.0
23.......	EE	−20.4	HH	−20.1	U	—[a]	F	−13.7	Z	−13.5	HH	−10.9	CC	−11.1
24.......	K	−37.1	K	−22.6	CC	—[a]	EE	−18.5	O	−17.7	K	−11.6	EE	−12.9

NOTE.—Specimens at the Pittsburgh and Rochester locations missing—stolen or destroyed some time between 1937 and 1941.

[a] Specimens missing.

and an attempt was made to correct such aging changes in the materials themselves by making tests of aged, uncorroded specimens when exposure specimens were removed from the racks after the 1-, 3-, 6-, and 10-yr. exposure periods. These "storage set" specimens were stored at the Bureau of Standards under the ordinary room temperature conditions prevailing over the intervening years, but since they were sealed in glass jars, they were presumably free from any corrosive attack by the atmosphere. However, these storage temperatures did not necessarily duplicate temperatures existing at the exposure locations. A study of the data resulting from tension tests on these storage set specimens, together with their standard deviations, shows that interesting changes have taken place in a number of the materials. In some cases these changes are difficult to explain, but they should be taken into account in arriving at a complete interpretation of the rest of the tension test data. Since we have been using these data in interpreting the results of our own tension tests on the corroded tension specimens, the subcommittee believes it is worth while to present in this report a compilation of the tension data on the storage specimens. The test results are given in Table I and are plotted in the form of curves in Figs. 1 to 5.

In checking the preprinted report of the Committee for 1944, it was found that, inadvertently, a change in the procedure for calculating the change in tensile strength had been made. Instead of referring the tension test results from specimens cut from the 9 by 12-in. plates to the 10-yr. storage specimens, to determine what change had taken place due to corrosion, they were referred to the tension test data from the initial specimens. The same error was made in determining the change in tensile strength for the tension specimens exposed on the test racks; and the change in tensile strength data, as published in the 1943 report, is, therefore, incorrect in this respect. The change in tensile strength data published in this report has been corrected accordingly for both the results from the tension specimens exposed on the test racks as well as those cut from the 9 by 12-in. plates.

In connection with material F, as explained in previous reports, the original materials for our tests were secured from two lots of metal. Detailed investigation in the course of tests made on the 10-yr. samples has shown that both lots of material were nonuniform in their tensile strength characteristics. This fact should be kept in mind in interpreting the tension data on material F appearing in the tables.

CONCLUSIONS

As stated in the 1943 report, it was planned to present in this year's report conclusions on the results of the tests made on the specimens after 10 yr. exposure. The problem of presenting conclusions drawn from these data is an extremely difficult one, in view of the large amount of test data involved. In the committee's opinion, the best way to summarize the data to obtain an overall picture of what changes have taken place and their significance is to present them in the form of tabulations called "graded summaries."

In these summaries, Tables II to V, inclusive, the changes in the materials, such as loss in weight, average penetration, changes in tensile strength, etc., have been arranged or graded in the order of the material showing the least amount to the material showing the greatest amount at each of the test locations. A study of a graded summary will, then, disclose which of the metals and alloys has suffered the least loss in tensile strength or weight at any one location. The amount of this change is indicated alongside the letter designating the material. In the case of the graded summary table of tension test data, the amount of change is reported as percentage change from the original.

In attempting to evaluate the significance of any individual percentage change, it is necessary not only to make allowance for changes in the material due to aging, as shown by the results of the 10-yr. tests on the storage specimens, but also to consider these changes with due regard to the standard deviations reported for the tension results in Tables VI to XII.

While a careful study of these graded summary tables might permit certain general conclusions to be drawn as to the relative corrosion resistance of the various metals and alloys in different types of atmospheres, it is the committee's opinion that a better survey and a more accurate statement of the value of the test data collected to date can be made by individuals most familiar with the corrosion performance of the particular metals and alloys. The committee, therefore, plans to sponsor a series of papers to be presented within the next year at a session of the Society devoted entirely to atmospheric corrosion of these non-ferrous metals and alloys, in which a discussion of the corrosion performance of the materials included in this investigation can be made by the authors of the papers more fully and more freely than would be possible by the committee acting as a whole, through the presentation of conclusions in its report. Arrangements have been made to have individuals present papers including the following:

(*a*) Copper and copper alloys—materials A, B, C, D, F, K, L, M, N, P, and Q;

(*b*) Zinc—materials AA, BB, and HH;

(*c*) Nickel and nickel alloys—materials S and T;

(*d*) Aluminum and aluminum alloys—materials I, O, Z, FF, and G;

(*e*) Lead and lead alloys and tin—materials U, CC, and EE; and

(*f*) Discussion of the significance of changes in storage specimens and discrepancies between data on loss in tensile strength and loss in weight.

This report has been submitted to letter ballot of the committee which consists of 37 voting members; 31 members returned their ballots, of whom 30 have voted affirmatively, 0 negatively, and 1 not voting.

Respectfully submitted on behalf of the subcommittee,

W. H. FINKELDEY,
Chairman

TABLE VI.—SUMMARY OF LOSS IN WEIGHT AND TENSION DATA AFTER 10-YR. EXPOSURE AT ALTOONA, PA.

Materials	Loss in Weight Data				Tension Data							
	Chemically Cleaned Plates				Change in Tensile Strength							
					Exposed as Machined Tension Specimens			Specimens Cut from 9 by 12-in. Plates after Chemical Cleaning			Specimens Cut from 9 by 12-in. Plates. Tensile strength calculated on basis of original area[a]	
	Average Loss, g.	Average Loss, oz. per sq. ft.	Average Loss, mg. per sq. cm.	Average Penetration, in. × 10^{-4}	Average, psi.	Standard Deviation, psi.	From Storage, per cent	Average, psi.	Standard Deviation, psi.	From Storage, per cent	Average, psi.	From Storage, per cent
A—Commercial copper (tough pitch) (99.9 + Cu, 0.026 O)	14.75	0.345	10.513	4.64	31 370	222.3	−6.8	33 930	263.9	−1.0	32 480	−5.3
B—Commercial copper (phosphorized) (99.9 + Cu, 0.007 P)	14.38	0.336	10.249	4.51	33 880	308.1	−5.9	34 560	187.0	−1.5	34 190	−2.5
C—Copper-silicon-manganese alloy (96 Cu, 3 Si, 1 Mn)	16.27	0.380	11.596	5.34	54 000	778.8	−7.7	62 030	317.6	−1.4	63 640	+1.2
D—Tin bronze (92 Cu, 8 Sn)	18.13	0.424	12.922	5.76	54 170	604.3	−7.2	56 360	302.0	+2.8	56 940	+3.8
F—Aluminum bronze (92 Cu, 8 Al)	18.73	0.438	13.349	6.73	70 300	737.1	−7.5	*	*	*	*	*
G—Commercial aluminum (99 + Al)	2.36	0.055	1.682	2.44	15 740	142.4	−7.0	16 400	150.7	−4.6	16 300	−5.2
I—Aluminum-manganese alloy (1 per cent Mn)	5.92	0.138	4.219	6.07	18 480	114.6	−10.4	19 630	128.4	−5.2	19 490	−5.9
K—Manganese bronze (high-tensile-strength yellow brass) (66.4 Cu, 19.3 Zn, 5.88 Al, 4.6 Fe, 3.78 Mn)	70.07	1.637	49.943	24.88	55 920	5197.0	−53.8	87 770	7346.0	−28.0	76 770	−37.1
L—Brass (85 Cu, 15 Zn)	26.95	0.630	19.208	8.62	37 230	499.8	−9.9	40 200	622.6	−2.3	38 960	−5.3
M—Brass (70 Cu, 30 Zn)	30.41	0.711	21.674	10.00	33 850	675.2	−30.9	44 340	482.1	−15.6	45 160	−14.0
N—Admiralty metal (70 Cu, 29 Zn, 1 Sn)	19.68	0.460	14.027	6.46	49 470	376.7	−9.0	53 010	165.4	−3.8	53 900	−2.2
O—Duralumin (4 Cu, 0.5 Mn, 0.5 Mg, balance Al)	5.25	0.123	3.741	5.27	55 360	306.0	−15.8	62 910	574.7	−5.2	62 510	−5.8
P—Copper-nickel-zinc alloy (75 Cu, 20 Ni, 5 Zn)	26.79	0.626	19.095	8.49	48 130	446.4	−8.7	53 910	196.6	−0.2	52 390	−3.1
Q—Copper-nickel-tin alloy (70 Cu, 29 Ni, 1 Sn)	26.25	0.613	18.709	8.30	69 850	1757.0	−11.4	66 580	191.1	−1.6	68 520	+1.2
S—Nickel-copper alloy (65 Ni, 32 Cu, 2 Fe, 1 Mn)	17.30	0.404	12.330	5.51	75 830	366.0	−4.5	77 590	1971.3	−2.6	79 100	−0.7
T—Commercial nickel (99 + Ni)	47.89	1.119	34.133	15.15	62 220	465.0	−15.0	71 820	1548.0	−2.1	71 510	−2.5
U—Chemical lead (99.92 Pb, 0.06 Cu)	10.82	0.253	7.712	2.67	2 370	30.6	+0.9	2 230	24.4	−0.4	2 190	−2.2
Z—Aluminum-magnesium-silicon alloy (98 Al, 0.5 Mg, 1 Si)	2.34	0.055	1.668	2.43	36 200	317.6	−15.3	38 580	763.5	−9.9	39 220	−8.5
AA—Commercial zinc (Prime Western Grade) (99 Zn, 0.85 Pb)	48.63	1.136	34.661	19.10	22 630	340.2	−22.2	28 110	204.5	−1.5	26 070	−8.7
BB—Commercial zinc (high grade) (99.9 + Zn)	49.31	1.152	35.146	19.31	13 870	268.6	−22.8	17 030	152.1	−2.8	16 310	−6.9
CC—Lead antimony alloy (1 per cent Sb)	8.65	0.202	6.165	2.14	3 080	12.6	−5.2	2 850	17.0	−6.6	2 840	−6.9
EE—Commercial tin (99.85 + Sn)	15.65	0.366	11.154	6.03	2 800	95.6	−15.9	2 960	25.6	−18.5	2 890	−20.4
FF—Aluminum-coated duralumin	2.60	0.061	1.853	2.64	58 790	422.7	−1.9	59 880	460.5	+1.1	59 270	+0.1
HH—Commercial zinc (special high grade 99.9 + Zn)	44.55	1.041	31.753	17.50	12 880	127.2	−22.8	16 600	182.4	−13.3	15 620	−18.4

[a] Specimen cross-sectional area = actual width × average original thickness.

* Data omitted; values obtained inconsistent due to nonuniformity in preparation of 9 by 12-in. plates exposed at this location.

TABLE VII.—SUMMARY OF LOSS IN WEIGHT AND TENSION DATA AFTER 10-YR. EXPOSURE AT NEW YORK, N. Y.

Materials	Loss in Weight Data				Tension Data							
					Change in Tensile Strength							
	Chemically Cleaned Plates				Exposed as Machined Tension Specimens			Specimens Cut from 9 by 12-in. Plates after Chemical Cleaning			Specimens Cut from 9 by 12-in. Plates. Tensile strength calculated on basis of original area[a]	
	Average Loss, g.	Average Loss, oz. per sq. ft.	Average Loss, mg. per sq. cm.	Average Penetration, in. × 10⁻⁴	Average, psi.	Standard Deviation, psi.	From Storage, per cent	Average, psi.	Standard Deviation, psi.	From Storage, per cent	Average, psi.	From Storage, per cent
A—Commercial copper (tough pitch) (99.9 + Cu, 0.026 O)	14.97	0.350	10.670	4.71	31 560	176.8	−6.2	33 910	111.1	−1.1	34 030	−0.7
B—Commercial copper (phosphorized) (99.9 + Cu, 0.007 P)	14.49	0.339	10.327	4.55	33 750	828.1	−6.3	34 820	221.4	−0.7	34 710	−1.1
C—Copper-silicon-manganese alloy (96 Cu, 3 Si, 1 Mn)	18.63	0.435	13.278	6.11	53 860	524.5	−7.9	62 440	259.5	−0.7	63 420	+0.9
D—Tin bronze (92 Cu, 8 Sn)	22.55	0.527	16.072	7.16	53 720	533.3	−8.0	55 790	699.5	+1.7	56 550	+3.1
F—Aluminum bronze (92 Cu, 8 Al)	18.67	0.436	13.307	6.71	68 620	1491.0	−9.7	*	*	*	*	*
G—Commercial aluminum (99 + Al)	3.04	0.071	2.166	3.15	15 860	91.15	−6.3	16 250	92.53	−5.5	16 010	−6.9
I—Aluminum-manganese alloy (1 per cent Mn)	3.92	0.092	2.794	4.02	19 370	125.5	−6.2	19 580	134.9	−5.5	19 890	−4.0
K—Manganese bronze (high-tensile-strength yellow brass) (66.4 Cu, 19.3 Zn, 5.88 Al, 4.6 Fe, 3.78 Mn)	59.23	1.384	42.216	21.00	56 520	4476.0	−53.3	97 110	3782.0	−20.4	94 420	−22.6
L—Brass (85 Cu, 15 Zn)	27.41	0.640	19.536	8.77	38 150	371.9	−7.6	40 580	587.7	−1.4	38 820	−5.7
M—Brass (70 Cu, 30 Zn)	26.35	0.616	18.781	8.66	35 180	118.0	−28.2	46 080	771.5	−12.2	47 770	−9.0
N—Admiralty metal (70 Cu, 29 Zn, 1 Sn)	23.10	0.540	16.464	7.58	50 080	581.7	−7.9	53 670	254.3	−2.6	54 060	−1.9
O—Duralumin (4 Cu, 0.5 Mn, 0.5 Mg, balance Al)	4.50	0.105	3.207	4.52	56 450	433.4	−14.1	62 020	402.3	−6.6	60 120	−9.4
P—Copper-nickel-zinc alloy (75 Cu, 20 Ni, 5 Zn)	22.67	0.530	16.158	7.18	48 850	340.6	−7.3	53 970	254.3	−0.1	52 810	−2.3
Q—Copper-nickel-tin alloy (70 Cu, 29 Ni, 1 Sn)	25.16	0.588	17.933	7.96	71 870	3497.0	−8.8	66 960	299.7	−1.1	67 680	0
S—Nickel-copper alloy (65 Ni, 32 Cu, 2 Fe, 1 Mn)	16.61	0.388	11.838	5.30	75 120	901.0	−5.4	81 130	1315.7	+1.9	80 620	+1.2
T—Commercial nickel (99 + Ni)	40.56	0.948	28.909	12.81	63 380	630.0	−13.4	74 280	1058.0	+1.3	72 800	−0.7
U—Chemical lead (99.92 Pb, 0.06 Cu)	6.77	0.158	4.825	1.67	2 370	30.96	+0.4	2 270	21.8	+1.3	2 220	−0.9
Z—Aluminum-magnesium-silicon alloy (98 Al, 0.5 Mg, 1 Si)	2.70	0.063	1.924	2.81	37 520	554.5	−12.2	39 030	948.0	−8.9	40 280	−6.0
AA—Commercial zinc (prime western grade) (99 Zn, 0.85 Pb)	49.25	1.151	35.103	19.32	23 070	220.8	−20.7	28 060	273.6	−1.7	25 990	−8.9
BB—Commercial zinc (high grade) (99.9 + Zn)	51.61	1.206	36.785	20.21	14 220	156.9	−20.9	17 440	92.7	−0.5	16 360	−6.6
CC—Lead antimony alloy (1 per cent Sb)	5.01	0.117	3.571	1.24	3 180	18.03	−2.2	2 940	32.1	−3.6	2 930	−3.9
EE—Commercial tin (99.85 + Sn)	12.25	0.286	8.731	4.71	2 930	63.79	−12.0	3 310	52.6	−8.9	3 320	−8.5
FF—Aluminum-coated duralumin	2.35	0.055	1.674	2.38	58 830	180.6	−1.9	60 410	528.3	+2.0	60 250	+1.8
HH—Commercial zinc (special high grade 99.9 + Zn)	48.78	1.140	34.768	19.13	14 670	563.0	−12.1	16 800	72.3	−12.3	15 300	−20.1

[a] Specimen cross-sectional area = actual width × average original thickness.

* Data omitted; values obtained inconsistent due to nonuniformity in preparation of 9 by 12-in. plates exposed at this location.

TABLE VIII.—SUMMARY OF LOSS IN WEIGHT AND TENSION DATA AFTER 10-YR. EXPOSURE AT SANDY HOOK, N. J.

Materials	Loss in Weight Data				Tension Data								
	Chemically Cleaned Plates				Change in Tensile Strength								
					Exposed as Machined Tension Specimens			Specimens Cut from 9 by 12-in. Plates after Chemical Cleaning			Specimens Cut from 9 by 12-in. Plates. Tensile strength calculated on basis of original area[a]		
	Average Loss, g.	Average Loss, oz. per sq. ft.	Average Loss, mg. per sq. cm.	Average Penetration, in. × 10^{-4}	Average, psi.	Standard Deviation, psi.	From Storage, per cent	Average, psi.	Standard Deviation, psi.	From Storage, per cent	Average, psi.	From storage, per cent	
A—Commercial copper (tough pitch) (99.9 + Cu, 0.026 O)	8.24	0.1925	5.873	2.58	32 510	118.0	−3.4	33 990	89.9	−0.8	34 660	+1.1	
B—Commercial copper (phosphorized) (99.9 + Cu, 0.007 P)	8.53	0.1992	6.079	2.67	34 770	178.9	−3.5	34 580	150.9	−1.4	34 480	−1.7	
C—Copper-silicon-manganese alloy (96 Cu, 3 Si, 1 Mn)	13.76	0.3214	9.807	4.51	55 390	612.3	−5.3	62 900	203.1	0	64 230	+2.1	
D—Tin bronze (92 Cu, 8 Sn)	15.59	0.3642	11.111	4.96	55 450	882.7	−5.0	55 530	791.9	+1.3	54 210	−1.1	
F—Aluminum bronze (92 Cu, 8 Al)	15.08	0.3523	10.748	5.43	72 070	887.9	−5.2	*	*	*	*	*	
G—Commercial aluminum (99 + Al)	0.21	0.0049	0.149	0.21	16 390	88.5	−3.1	16 700	284.4	−2.9	16 680	−3.0	
I—Aluminum-manganese alloy (1 per cent Mn)	0.51	0.0119	0.363	0.52	20 020	56.79	−3.0	20 790	151.0	+0.4	20 690	−0.1	
K—Manganese bronze (high-tensile-strength yellow brass) (66.4 Cu, 19.3 Zn, 5.88 Al, 4.6 Fe, 3.78 Mn)	30.00	0.7009	21.382	10.61	97 680	3616.0	−19.4	102 880	9207.0	−15.7	99 590	−18.3	
L—Brass (85 Cu, 15 Zn)	14.68	0.3429	10.463	4.70	39 410	417.1	−4.6	40 560	360.4	−1.5	39 880	−3.1	
M—Brass (70 Cu, 30 Zn)	11.97	0.2796	8.531	3.93	43 100	182.6	−12.0	48 570	1010.0	−7.5	49 830	−5.1	
N—Admiralty metal (70 Cu, 29 Zn, 1 Sn)	13.66	0.3191	9.736	4.48	51 500	191.5	−5.2	54 340	217.6	−1.4	54 610	−0.9	
O—Duralumin (4 Cu, 0.5 Mn, 0.5 Mg, balance Al)	0.16	0.004	0.114	0.16	58 470	270.1	−11.0	63 840	794.4	−3.8	64 100	−3.4	
P—Copper-nickel-zinc alloy (75 Cu, 20 Ni, 5 Zn)	12.95	0.3025	9.230	4.10	50 460	303.9	−4.3	54 030	222.8	.0	53 660	−0.7	
Q—Copper-nickel-tin alloy (70 Cu, 29 Ni, 1 Sn)	13.77	0.3217	9.814	4.35	72 950	4403.0	−7.4	66 890	160.0	−1.2	69 860	+3.2	
S—Nickel-copper alloy (65 Ni, 32 Cu, 2 Fe, 1 Mn)	7.89	0.1843	5.623	2.51	76 650	266.0	−3.5	77 970	1285.6	−2.1	78 470	−1.5	
T—Commercial nickel (99 + Ni)	9.35	0.2184	6.664	2.96	70 930	381.0	−3.1	70 330	1268.0	−4.1	72 080	−1.7	
U—Chemical lead (99.92 Pb, 0.06 Cu)	....	....	....	....	2 310	71.15	−1.7	....	....	....	missing	....	
Z—Aluminum-magnesium-silicon alloy (98 Al, 0.5 Mg, 1 Si)	0.36	0.0084	0.256	0.37	38 820	613.6	−9.1	41 800	658.2	−2.4	43 730	+2.1	
AA—Commercial zinc (prime western grade) (99 Zn, 0.85 Pb)	14.10	0.3294	10.049	5.54	27 130	180.0	−6.7	28 560	176.7	+0.1	29 600	+3.7	
BB—Commercial zinc (high grade) (99.9 + Zn)	14.25	0.3329	10.156	5.59	16 750	170.8	−6.8	17 430	91.64	−5.2	17 710	+1.1	
CC—Lead antimony alloy (1 per cent Sb)	....	....	....	....	3 130	31.09	−3.7	....	....	....	missing	....	
EE—Commercial tin (99.85 + Sn)	....	....	....	....	2 710	47.94	−18.6	....	....	....	missing	....	
FF—Aluminum-coated duralumin	0.57	0.0133	0.406	0.57	57 180	186.4	−4.6	59 860	717.2	+1.1	60 330	+1.9	
HH—Commercial zinc (special high grade 99.9 + Zn)	13.85	0.3235	9.871	5.44	16 740	110.6	+0.3	17 510	139.5	−8.6	16 950	−11.5	

[a] Specimen cross-sectional area = actual width × average original thickness.

* Data omitted; values obtained inconsistent due to nonuniformity in preparation of 9 by 12-in. plates exposed at this location.

TABLE IX.—SUMMARY OF LOSS IN WEIGHT AND TENSION DATA AFTER 10-YR. EXPOSURE AT KEY WEST, FLA.

Materials	Loss in Weight Data				Tension Data							
	Chemically Cleaned Plates				Change in Tensile Strength							
					Exposed as Machined Tension Specimens			Specimens Cut from 9 by 12-in. Plates after Chemical Cleaning			Specimens Cut from 9 by 12-in. Plates. Tensile strength calculated on basis of original area[a]	
	Average Loss, g.	Average Loss, oz. per sq. ft.	Average Loss, mg. per sq. cm.	Average Penetration, in. × 10^{-4}	Average, psi.	Standard Deviation, psi.	From Storage, per cent	Average, psi.	Standard Deviation, psi.	From Storage, per cent	Average, psi.	From Storage, per cent
A—Commercial copper (tough pitch) (99.9 + Cu, 0.026 O)	6.31	0.1474	4.497	1.98	33 070	146.2	−1.8	34 210	204.5	−0.2	34 620	+1.0
B—Commercial copper (phosphorized) (99.9 + Cu, 0.007 P)	6.56	0.1532	4.675	2.05	35 480	122.3	−1.5	34 730	164.8	−1.0	35 040	−0.1
C—Copper-silicon-manganese alloy (96 Cu, 3 Si, 1 Mn)	12.03	0.2810	8.574	3.94	56 810	688.2	−2.9	62 590	281.7	−0.5	64 680	+2.9
D—Tin bronze (92 Cu, 8 Sn)	9.66	0.2257	6.885	3.06	56 150	981.1	−3.8	57 070	577.4	+4.1	56 410	+2.9
F—Aluminum bronze (92 Cu, 8 Al)	3.60	0.0841	2.565	1.29	73 570	3150.0	−3.2	*	*	*	*	*
G—Commercial aluminum (99 + Al)	0.35	0.0081	0.249	0.36	16 640	266.6	−1.7	17 230	200.6	+0.2	16 960	−1.3
I—Aluminum-manganese alloy (1 per cent Mn)	0.33	0.0077	0.235	0.34	20 540	167.6	−0.5	20 750	77.66	+0.2	20 770	+0.3
K—Manganese bronze (high-tensile-strength yellow brass) (66.4 Cu, 19.3 Zn, 5.88 Al, 4.6 Fe, 3.78 Mn)	15.66	0.3658	11.161	5.56	105 030	10 720.0	−13.3	111 860	4596.0	−8.3	117 580	−3.6
L—Brass (85 Cu, 15 Zn)	5.81	0.1357	4.141	1.86	40 730	336.3	−1.4	40 720	447.1	−1.1	39 960	−2.9
M—Brass (70 Cu, 30 Zn)	4.40	0.103	3.136	1.45	48 000	772.4	−2.0	50 830	539.1	−3.2	51 810	−1.3
N—Admiralty metal (70 Cu, 29 Zn, 1 Sn)	4.39	0.1025	3.129	1.44	53 320	176.2	−1.9	54 130	227.8	−1.7	55 460	+0.8
O—Duralumin (4 Cu, 0.5 Mn, 0.5 Mg, balance Al)	0.64	0.015	0.456	0.64	62 290	810.2	−5.2	66 260	619.9	−0.2	66 190	−0.3
P—Copper-nickel-zinc alloy (75 Cu, 20 Ni, 5 Zn)	3.69	0.0862	2.630	1.17	51 700	328.8	−1.9	53 480	159.0	−1.0	52 600	−2.7
Q—Copper-nickel-tin alloy (70 Cu, 29 Ni, 1 Sn)	4.43	0.104	3.158	1.40	75 930	5503.0	−3.6	67 160	215.0	−0.8	70 430	+4.1
S—Nickel-copper alloy (65 Ni, 32 Cu, 2 Fe, 1 Mn)	1.92	0.0448	1.368	0.61	79 900	896.0	+0.6	80 240	1367.7	+0.7	83 360	+4.7
T—Commercial nickel (99 + Ni)	1.49	0.0348	1.062	0.47	72 700	709.0	−0.6	72 840	1403.0	−0.7	75 420	+2.8
U—Chemical lead (99.92 Pb. 0.06 Cu)	8.77	0.2049	6.250	2.16	2 350	28.95	0	2 240	24.9	0	2 210	−1.3
Z—Aluminum-magnesium-silicon alloy (98 Al, 0.5 Mg. 1 Si)	0.18	0.004	0.128	0.19	41 150	317.4	−3.7	43 470	439.5	+1.5	45 510	+6.2
AA—Commercial zinc (prime western grade) (99 Zn, 0.85 Pb)	5.24	0.1224	3.734	2.05	28 530	149.7	−1.9	29 080	209.8	+1.9	29 690	+4.0
BB—Commercial zinc (high grade) (99.9 + Zn)	4.57	0.1067	3.257	1.79	17 470	93.66	−2.8	17 600	122.5	+0.5	18 050	+3.0
CC—Lead antimony alloy (1 per cent Sb)	8.28	0.1934	5.901	2.05	3 060	41.13	−5.8	2 760	48.6	−9.5	2 740	−10.2
EE—Commercial tin (99.85 + Sn)	21.90	0.5116	15.609	8.41	2 780	97.77	−16.5	3 050	69.6	−16.0	2 960	−18.5
FF—Aluminum-coated duralumin	0.13	0.0030	0.092	0.13	60 300	339.8	+0.6	60 890	344.6	+2.9	60 690	+2.5
HM—Commercial zinc (special high grade 99.9 + Zn)	3.84	0.0897	2.736	1.50	17 520	160.3	+5.0	17 850	93.6	−6.8	17 390	−9.2

[a] Specimen cross-sectional area = actual width × average original thickness.

* Data omitted; values obtained inconsistent due to nonuniformity in preparation of 9 by 12-in. plates exposed at this location.

TABLE X.—SUMMARY OF LOSS IN WEIGHT AND TENSION DATA AFTER 10-YR. EXPOSURE AT LA JOLLA, CALIF.

Materials	Loss in Weight Data				Tension Data							
	Chemically Cleaned Plates				Change in Tensile Strength							
					Exposed as Machined Tension Specimens			Specimens Cut from 9 by 12-in. Plates after Chemical Cleaning			Specimens Cut from 9 by 12-in. Plates. Tension strength calculated on basis of original area[a]	
	Average Loss, g.	Average Loss, oz. per sq. ft.	Average Loss, mg. per sq. cm.	Average Penetration, in. × 10^{-4}	Average, psi.	Standard Deviation, psi.	From Storage, per cent	Average, psi.	Standard Deviation, psi.	From Storage, per cent	Average, psi.	From Storage, per cent
4—Commercial copper (tough pitch) (99.9 + Cu, 0.026 O)	16.58	0.387	11.817	5.21	30 300	349.5	−10.0	33 990	224.9	−0.8	32 520	−5.1
B—Commercial copper (phosphorized) (99.9 + Cu, 0.007 P)	13.96	0.326	9.950	4.39	33 300	191.5	−7.6	34 880	181.0	−0.6	34 830	−0.7
C—Copper-silicon-manganese alloy (96 Cu, 3 Si, 1 Mn)	22.74	0.531	16.208	7.46	55 510	1402.0	−5.1	61 980	248.0	−1.4	63 790	+1.4
D—Tin bronze (92 Cu, 8 Sn)	25.61	0.598	18.253	8.14	55 030	732.1	−5.7	56 780	531.8	+3.5	55 920	+2.0
F—Aluminum bronze (92 Cu, 8 Al)	2.18	0.0509	1.553	0.78	83 220	1055.0	−1.4	82 430	590.2	−4.0	80 190	−6.6
G—Commercial aluminum (99 + Al)	2.72	0.063	1.938	2.81	14 530	520.0	−14.1	16 180	347.6	−5.9	16 260	−5.3
I—Aluminum-manganese alloy (1 per cent Mn)	2.20	0.051	1.568	2.26	19 080	348.8	−7.6	20 250	108.9	−2.2	20 150	−2.7
K—Manganese bronze (high-tensile-strength yellow brass) (66.4 Cu, 19.3 Zn, 5.88 Al, 4.6 Fe, 3.78 Mn)	17.21	0.402	12.266	6.10	92 800	8159.0	−23.4	108 660	7390.0	−10.9	109 830	−9.9
L—Brass (85 Cu, 15 Zn)	7.38	0.172	5.260	2.36	39 870	600.9	−3.5	40 810	598.7	−0.9	40 200	−2.3
M—Brass (70 Cu, 30 Zn)	3.50	0.081	2.494	1.15	45 070	508.5	−8.0	50 290	734.5	−4.2	51 620	−1.7
N—Admiralty metal (70 Cu, 29 Zn, 1 Sn)	4.69	0.109	3.342	1.54	53 000	326.6	−2.5	54 440	217.9	−1.2	55 940	+1.5
O—Duralumin (4 Cu, 0.5 Mn, 0.5 Mg, balance Al)	5.71	0.133	4.069	5.73	32 500	225.0	−50.5	55 630	3526.0	−16.2	54 630	−17.7
P—Copper-nickel-zinc alloy (75 Cu, 20 Ni, 5 Zn)	3.81	0.089	2.715	1.21	51 670	653.8	−2.0	53 760	154.0	−0.5	53 320	−1.3
Q—Copper-nickel-tin alloy (70 Cu, 29 Ni, 1 Sn)	3.37	0.078	2.401	1.06	76 470	5246.0	−3.0	67 320	200.7	−0.5	70 340	+3.9
S—Nickel-copper alloy (65 Ni, 32 Cu, 2 Fe 1, 1 Mn	2.22	0.051	1.582	0.70	79 870	1987.0	+0.6	80 900	1771.6	+1.6	82 380	+3.4
T—Commercial nickel (99 + Ni)	1.38	0.032	0.984	0.43	72 270	947.0	−1.2	72 670	972.2	−0.9	75 440	+2.8
U—Chemical lead (99.92 Pb, 0.06 Cu)	6.56	0.153	4.675	1.62	2 390	23.8	+1.7	2 210	23.4	−1.3	2 200	−1.8
Z—Aluminum-magnesium-silicon alloy (98 Al, 0.5 Mg, 1 Si)	2.41	0.056	1.717	2.51	31 130	159.1	−27.1	36 540	1002.0	−14.7	37 060	−13.5
AA—Commercial zinc (prime western grade) (99 Zn, 0.85 Pb)	17.45	0.407	12.437	6.85	25 900	365.1	−10.9	28 730	391.7	+0.7	29 230	+2.4
BB—Commercial zinc (high grade) (99.9 + Zn)	16.00	0.373	11.404	6.29	16 080	90.35	−10.5	17 350	145.8	−1.0	17 770	+1.4
CC—Lead antimony alloy (1 per cent Sb)	9.56	0.223	6.813	2.36	3 050	75.28	−6.2	2 870	25.5	−5.9	2 830	−7.2
EE—Commercial tin (99.85 + Sn)	23.51	0.549	16.756	9.05	2 410	183.0	−27.6	3 170	37.11	−12.7	3 160	−12.9
FF—Aluminum-coated duralumin	1.61	0.037	1.147	1.63	58 730	100.1	−2.0	59 520	984.4	+0.5	60 330	+1.9
HH—Commercial zinc (special high grade 99.9 + Zn)	12.25	0.286	8.731	4.81	16 410	151.7	−1.7	17 710	137.8	−7.5	17 260	−9.9

[a] Specimen cross-sectional area = actual width × average thickness.

TABLE XI.—SUMMARY OF LOSS IN WEIGHT AND TENSION DATA AFTER 10-YR. EXPOSURE AT STATE COLLEGE, PA.

Materials	Loss in Weight Data				Tension Data							
	Chemically Cleaned Plates				Change in Tensile Strength							
					Exposed as Machined Tension Specimens			Specimens Cut from 9 by 12-in. Plates after Chemical Cleaning			Specimens Cut from 9 by 12-in. Plates. Tension strength calculated on basis of original area[a]	
	Average Loss, g.	Average Loss, oz. per sq. ft.	Average Loss, mg. per sq. cm.	Average Penetration, in. × 10^{-4}	Average, psi.	Standard Deviation, psi.	From Storage, per cent	Average, psi.	Standard Deviation, psi.	From Storage, per cent	Average, psi.	From Storage, per cent
A—Commercial copper (tough pitch) (99.9 + Cu, 0.026 O)	7.23	0.169	5.153	2.28	32 260	139.3	−4.2	33 910	147.8	−1.1	34 490	+0.6
B—Commercial copper (phosphorized) (99.9 + Cu, 0.007 P)	6.61	0.154	4.711	2.07	34 920	176.5	−3.1	34 730	201.6	−1.0	34 750	−0.9
C—Copper-silicon-manganese alloy (96 Cu, 3 Si, 1 Mn)	5.69	0.132	4.055	1.86	57 020	1009.0	−2.5	62 540	329.5	−0.5	65 210	+3.7
D—Tin bronze (92 Cu, 8 Sn)	4.11	0.096	2.929	1.31	56 570	1058.0	−3.1	55 440	295.5	+1.1	54 370	−0.9
F—Aluminum bronze (92 Cu, 8 Al)	2.16	0.050	1.539	0.77	74 230	1963.0	−2.4	*	*	*	*	*
G—Commercial aluminum (99 + Al)	0.12	0.002	0.085	0.12	16 940	134.7	+0.1	16 770	145.2	−2.4	16 520	−3.9
I—Aluminum-manganese alloy (1 per cent Mn)	0.09	0.002	0.064	0.09	20 580	122.7	−0.3	20 630	131.0	−0.4	20 520	−0.9
K—Manganese bronze (high-tensile-strength yellow brass) (66.4 Cu, 19.3 Zn, 5.88 Al, 4.6 Fe, 3.78 Mn)	3.59	0.083	2.558	1.27	123 630	10 910.0	+2.1	111 260	6466.0	−8.8	107 860	−11.6
L—Brass (85 Cu, 15 Zn)	9.22	0.215	6.571	3.01	39 760	186.5	−3.7	40 520	382.4	−1.6	40 020	−2.8
M—Brass (70 Cu, 30 Zn)	4.74	0.110	3.378	1.55	47 420	737.8	−3.2	50 160	375.6	−4.5	52 420	−0.2
N—Admiralty metal (70 Cu, 29 Zn, 1 Sn)	4.80	0.112	3.421	1.57	53 150	364.0	−2.2	54 140	149.9	−1.7	55 820	+1.3
O—Duralumin (4 Cu, 0.5 Mn, 0.5 Mg, balance Al)	0.21	0.004	0.149	0.21	65 020	109.0	−1.0	64 770	1372.0	−2.4	63 730	−4.0
P—Copper-nickel-zinc alloy (75 Cu, 20 Ni, 5 Zn)	4.36	0.101	3.107	1.38	51 880	625.1	−1.6	54 140	157.6	+0.2	54 680	+1.2
Q—Copper-nickel-tin alloy (70 Cu, 29 Ni, 1 Sn)	4.36	0.101	3.107	1.37	77 600	6767.0	−1.5	67 030	248.7	−1.0	70 270	+3.8
S—Nickel-copper alloy (65 Ni, 32 Cu, 2 Fe, 1 Mn)	1.47	0.034	1.047	0.46	79 600	392.0	+0.2	79 170	1714.3	−0.6	80 090	+0.6
T—Commercial nickel (99 + Ni)	1.95	0.045	1.389	0.61	72 580	286.0	−0.8	72 370	1082.0	−1.3	75 290	+2.6
U—Chemical lead (99.92 Pb, 0.06 Cu)	7.64	0.178	5.445	1.88	2 380	68.1	+1.3	2 210	13.6	−1.6	2 100	−6.3
Z—Aluminum-magnesium-silicon alloy (98 Al, 0.5 Mg, 1 Si)	0.16	0.003	0.114	0.16	41 930	863.7	−1.8	42 720	339.6	−2.0	43 710	+2.0
AA—Commercial zinc (prime western grade) (99 Zn, 0.85 Pb)	10.70	0.250	7.627	4.20	27 330	256.4	−6.0	28 440	340.7	−0.4	29 910	+4.8
BB—Commercial zinc (high grade) (99.9 + Zn)	8.73	0.203	6.222	3.42	17 130	94.88	−4.7	17 280	55.9	−1.4	17 670	+1.4
CC—Lead antimony alloy (1 per cent Sb)	5.23	0.122	3.727	1.29	3 150	29.30	−3.1	2 890	14.2	−5.2	2 880	−5.6
EE—Commercial tin (99.85 + Sn)	4.55	0.106	3.243	1.75	3 040	80.83	−8.7	3 410	23.5	−6.1	3 450	−5.0
FF—Aluminum-coated duralumin	0.10	0.002	0.071	0.10	59 590	637.5	−0.6	60 060	726.8	+1.5	59 810	+1.0
HH—Commercial zinc (special high grade 99.9 + Zn)	9.11	0.212	6.493	3.57	17 240	245.0	+3.3	17 610	167.3	−8.0	17 070	−10.9

[a] Specimen cross-sectional area = actual width × average original thickness.

* Data omitted; values obtained inconsistent due to nonuniformity in preparation of 9 by 12-in. plates exposed at this location.

TABLE XII.—SUMMARY OF LOSS IN WEIGHT AND TENSION DATA AFTER 10-YR. EXPOSURE AT PHOENIX, ARIZ.

Materials	Loss in Weight Data				Tension Data								
					Change in Tensile Strength								
	Chemically Cleaned Plates				Exposed as Machined Tension Specimens			Specimens Cut from 9 by 12-in. Plates after Chemical Cleaning			Specimens Cut from 9 by 12-in. Plates. Tensile strength calculated on basis of original area[a]	
	Average Loss, g.	Average Loss, oz. per sq. ft.	Average Loss, mg. per sq.cm.	Average Penetration, in. × 10⁻⁴	Average, psi.	Standard Deviation, psi.	From Storage, per cent	Average, psi.	Standard Deviation, psi.	From Storage, per cent	Average, psi.	From Storage, per cent
A—Commercial copper (tough pitch) (99.9 + Cu, 0.026 O)	1.71	0.039	1.218	0.53	33 380	167.3	−0.8	34 240	149.9	−0.1	34 950	+2.0
B—Commercial copper (phosphorized) (99.9 + Cu, 0.007 P)	1.44	0.033	1.026	0.45	35 830	125.7	−0.5	35 280	194.4	+0.6	35 540	+1.3
C—Copper-silicon-manganese alloy (96 Cu, 3 Si, 1 Mn)	2.14	0.050	1.525	0.70	57 570	598.3	−1.6	62 990	269.0	+0.2	65 730	+4.5
D—Tin bronze (92 Cu, 8 Sn)	1.99	0.046	1.418	0.63	58 030	1078.0	−0.6	57 410	725.3	+4.7	57 430	+4.7
F—Aluminum bronze (92 Cu, 8 Al)	0.69	0.016	0.491	0.24	83 020	891.2	−1.7	82 430	1644.0	−4.0	81 680	+4.9
G—Commercial aluminum (99 + Al)	0.01	0.0002	0.007	0.01	16 630	292.1	−1.7	16 860	217.2	−1.7	16 950	−1.4
I—Aluminum-manganese alloy (1 per cent Mn)	0.01	0.0002	0.007	0.01	20 830	237.9	+0.9	20 870	137.8	+0.8	20 730	+0.1
K—Manganese bronze (high-tensile-strength yellow brass) (66.4 Cu, 19.3 Zn, 5.88 Al, 4.6 Fe, 3.78 Mn)	1.29	0.030	0.919	0.45	117 150	5483.0	−3.3	120 730	6508.0	−1.0	118 920	−2.5
L—Brass (85 Cu, 15 Zn)	1.25	0.029	0.890	0.40	41 210	501.5	−0.2	41 560	571.6	+1.0	40 960	−0.5
M—Brass (70 Cu, 30 Zn)	1.36	0.031	0.969	0.44	48 870	426.5	−0.2	51 190	791.7	−2.5	52 440	−0.1
N—Admiralty metal (70 Cu, 29 Zn, 1 Sn)	1.19	0.027	0.848	0.39	54 050	450.0	−0.6	54 530	286.1	−1.0	56 000	+1.7
O—Duralumin (4 Cu, 0.5 Mn, 0.5 Mg., balance Al)	0.04	0.0009	0.028	0.04	65 560	634.9	−0.2	66 920	583.3	+0.8	65 800	−0.9
P—Copper-nickel-zinc alloy (75 Cu, 20 Ni, 5 Zn)	1.12	0.026	0.798	0.35	52 520	425.4	−0.4	53 690	178.4	−0.6	53 200	−1.6
Q—Copper-nickel-tin alloy (70 Cu, 29 Ni, 1 Sn)	0.95	0.022	0.677	0.30	80 850	5493.0	+2.6	67 380	162.9	−0.4	70 520	+4.2
S—Nickel-copper alloy (65 Ni, 32 Cu, 2 Fe, 1 Mn)	0.48	0.011	0.342	0.15	79 100	1359.0	−0.4	79 870	1152.4	+0.3	80 770	+1.4
T—Commercial nickel (99 + Ni)	0.37	0.008	0.263	0.12	71 700	493.0	−2.0	73 800	1187.0	+0.6	75 900	+3.5
U—Chemical lead (99.92 Pb, 0.06 Cu)	3.84	0.089	2.736	0.94	2 410	37.86	+2.6	2 230	12.5	−0.4	2 190	−2.2
Z—Aluminum-magnesium-silicon alloy (98 Al, 0.5 Mg, 1 Si)	0.02	0.0004	0.014	0.02	43 450	557.7	+1.7	44 780	238.5	+4.5	44 830	+4.6
AA—Commercial zinc (prime western grade) (99 Zn, 0.85 Pb)	2.53	0.059	1.803	0.99	28 530	250.0	−1.9	29 140	237.1	+2.1	30 650	+7.4
BB—Commercial Zinc (high grade) (99.9 + Zn)	1.79	0.041	1.275	0.70	17 720	35.65	−1.4	17 410	74.74	−0.6	17 810	+1.7
CC—Lead antimony alloy (1 per cent Sb)	4.39	0.102	3.129	1.09	3 040	41.53	−6.5	2 730	26.0	−10.5	2 710	−11.1
EE—Commercial tin (99.85 + Sn)	3.32	0.077	2.366	1.28	2 920	43.97	−12.3	3 120	40.2	−14.0	3 160	−12.9
FF—Aluminum-coated duralumin	0.01	0.0002	0.007	0.10	59 300	993.8	−1.1	60 470	2938.0	+2.1	60 400	+2.0
HH—Commercial zinc (special high grade 99.9 + Zn)	1.18	0.027	0.841	0.46	17 960	112.3	+7.6	17 850	100.1	−6.8	17 800	−7.0

---

[a] Specimen cross-sectional area = actual width × average thickness.

REPORT OF COMMITTEE B-4

ON

ELECTRICAL-HEATING, ELECTRICAL-RESISTANCE AND ELECTRIC-FURNACE ALLOYS

Committee B-4 on Electrical-Heating, Electrical-Resistance and Electric-Furnace Alloys held three meetings during the year: in Pittsburgh, Pa., on June 29 and 30, 1943, and in New York, N. Y., on October 7 and 8, 1943, and February 21, 1944.

The committee consists of 56 members, of whom 28 are classified as producers, 22 as consumers, and 6 as general interest members.

A Bibliography and Abstracts on Electrical Contacts with about 800 references to articles relating to electrical contacts and circuit interruption, and contact materials, has been prepared by Subcommittee X on Contact Materials. This probably is the most complete list of references on this subject which has been compiled. It has been published by the Society, and already a considerable number of copies have been sold. It is to be kept up to date by publishing yearly a booklet containing new references.

I. New Tentative Standards

The committee recommends that the following specifications and methods of test[1] be accepted for publication as tentative:

Tentative Specifications for:

Chromium-Nickel-Iron Alloy Castings (25-12 Class) for High-Temperature Service, and

Tentative Methods of Test for:

Equivalent Yield Stress of Thermostat Metals.

II. Tentative Revisions of Standards

Standard Specifications for Drawn or Rolled Alloy, 80 per cent Nickel, 20 per cent Chromium, for Electrical Heating Elements (**B 82 - 41**)[2] *and Standard Specifications for Drawn or Rolled Alloy, 60 per cent Nickel, 15 per cent Chromium, and Balance Iron, for Electrical Heating Elements* (**B 83 - 41**).[2]—The committee recommends for publication as tentative revisions of these specifications which include changes in the sections on nominal resistivity, nominal electrical resistance and tolerances on electrical resistance per unit length, resistance change with temperature, and on packing. These revisions have been incorporated in completely revised specifications which are recommended for publication as tentative as appended hereto.[1]

III. Tentative Standards Continued as Tentative

It is recommended that the following tentative standards be continued as tentative without change:

Methods of Testing Nickel and Nickel-Alloy Wire and Ribbon for Electronic Tube Filaments (B 118 - 42 T),

Method of Test for Temper of Strip and Sheet Metals for Electronic Devices (Spring-Back Method) (B 155 - 41 T),

Methods of Testing Lateral Wire for Grids of Electronic Devices (B 156 - 42 T),

Methods of Testing Wire for Supports Used in Electronic Devices and Lamps (B 157 - 41 T),

Specifications for Round Nickel Wire for Lamps and Electronic Devices (B 175 - 42 T).

---

[1] These specifications and methods were accepted as tentative by the Society and appear in the 1944 Book of A.S.T.M. Standards, Part I.

[2] 1942 Book of A.S.T.M. Standards, Part I.

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 56 members, with the results shown in Table I.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Life Tests (J. W. Harsch, chairman).—Revisions in the Standard Specifications for Drawn or Rolled Alloy, 80 per cent Nickel, 20 per cent Chromium, for Electrical Heating Elements (B 82 – 41), and for Drawn or Rolled Alloy, 60 per cent Nickel, 15 per cent Chromium, and Balance Iron (B 83 – 41) have been recommended by this subcommittee, as mentioned earlier in this report, for publication as tentative to bring the specifications in line with present commercial practice.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. NEW TENTATIVE STANDARDS			
Spec. for Chromium-Nickel-Iron Alloy Castings (25–12 Class) for High Temperature Service	20	2	10
Test for Equivalent Yield Stress of Thermostat Metals	41	0	7
II. TENTATIVE REVISIONS OF STANDARDS			
Spec. for Drawn or Rolled Alloy, 80 per cent Nickel, 20 per cent Chromium, for Electrical Heating Elements (B 82 – 41)	41	0	7
Spec. for Drawn or Rolled Alloy, 60 per cent Nickel, 15 per cent Chromium, and Balance Iron, for Electrical Heating Elements (B 83 – 41)	44	0	4

Subcommittee V on Wrought and Cast Alloys for High-Temperature Use (J. W. Harsch, chairman).—The subcommittee has continued its work on the Proposed Specifications for Chromium-Nickel-Iron Alloy Castings (25–12 Class) for High-Temperature Service,[3] which were published as information with the 1942 Report of Committee B-4. The creep test has been omitted as an acceptance test because of the prohibitively long time and expense involved. These specifications have been prepared in cooperation with Committee A-10 on Iron-Chromium, Iron-Chromium-Nickel and Related Alloys. The specifications as revised[1] are being recommended for publication as tentative.

It has been decided to collect and correlate data looking toward the preparation of specifications for alloy castings composed of 35 per cent chromium, 16 per cent nickel and balance iron, for electric furnace applications.

Subcommittee VII on Thermostat Metals (P. H. Brace, chairman).—The Proposed Method of Test for Equivalent Yield Stress of Thermostat Metals[1] which was published as information with the 1943 Report of Committee B-4 has been given further trial during the year and has been found very effective. The method is now being recommended for publication as tentative. The wide variety of physical properties in the various grades of thermostat metals makes necessary a further study of stabilizing pretreatment of test specimens.

It has been decided to undertake the development of methods of test for the elastic properties of special purpose spring alloys in wire and strip form, at elevated temperatures. These alloys are of considerable interest because of their usefulness in vital parts of measurement and control devices. As the tests are rather closely related to those used for thermostat metals, they have been assigned to this subcommittee.

Subcommittee VIII on Metallic Materials for Radio and Incandescent Lamps (S. A. Standing, chairman).—Methods of test are being studied for the determination of particle size and distribution of powdered materials used in electronic tubes and incandescent lamps. These include such items as cathode coating, fluorescent materials, and tungsten powder.

---

[3] *Proceedings*, Am. Soc. Testing Mats., Vol. 42, p. 176 (1942).

Improved methods of determining flaws in tungsten wire are also being studied.

Subcommittee IX on Methods of Test for Alloys in Controlled Atmospheres (P. H. Brace, chairman).—Further experimental work on the effect of sulfur has been delayed because of the War Program, but will be continued. The application of the method to cast as well as wrought alloys also will be considered.

Subcommittee X on Contact Materials (F. E. Carter, chairman).—The problems involved in standardizing the testing of electrical contact materials are complex, and it has been found that the results obtained with a testing machine are extremely critical to the design and inherent characteristics of the individual machines. The mechanical construction of the device for operating the contacts of the machine described in the Tentative Method for Life Test of Electrical Contact Materials (B 182 – 43 T) has been given considerable study, and the improvements made have produced closer correlation of tests between laboratories and it is expected that reproducible tests can be made.

The same complexity of investigation is to be expected in some of the other fields which are being considered by the committee. These are included in the Section on Load Carrying Capacity of Contacts, which is considering the problems of contact welding, contact burning under severe arcing conditions, hardness, specific resistance of contact materials, and other factors. This work is still in a preliminary state, except that some interesting results have been worked out by the investigators using the life test machine on the problem of contact welding.

Following the standardization work on solid contact rivets to reduce the number of sizes to a minimum, which was done in connection with the National Electrical Manufacturers Association, further work on standardizing contact shapes and sizes has included steel back and projection welding contacts. Composite rivets and screw type contacts will be considered later.

The Bibliography and Abstracts on Electrical Contacts prepared by the subcommittee and published by the Society has been well received, as mentioned earlier in this report.

The present officers of the committee have been re-elected for the ensuing term of two years.

This report has been submitted to letter ballot of the committee which consists of 56 members; 48 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

DEAN HARVEY,
Chairman.

F. E. BASH,
Secretary.

REPORT OF COMMITTEE B-5

ON

COPPER AND COPPER ALLOYS, CAST AND WROUGHT

Committee B-5 on Copper and Copper Alloys, Cast and Wrought, held one meeting during the year: in Cincinnati, Ohio, on March 1, 1944. At this time a number of the subcommittees also met.

During the year the committee lost by death J. E. Schmeltzer who for some years represented the U. S. Maritime Commission.

At the present time the committee consists of 117 members of whom 100 are voting members; 42 are classified as producers, 42 as consumers, and 16 as general interest members.

Recommendations Accepted by Committee E-10 on Standards

Subsequent to the Annual Meeting, Committee B-5 presented to the Society through Committee E-10 on Standards the following recommendations under the emergency procedure:

Emergency Alternate Provisions in:

Standard Specifications for Steam or Valve Bronze Castings (EA - B 61),

Standard Specifications for Free-Cutting Brass Rod for Use in Screw Machines (EA - B 16),

Standard Specifications for Castings of the Alloy: Copper 88 per cent, Tin 8 per cent, Zinc 4 per cent (EA - B 60a),

Standard Specifications for Composition Brass or Ounce Metal Castings (EA - B 62a),

Tentative Specifications for Bronze Castings for Turntables and Movable Bridges and for Bearing and Expansion Plates of Fixed Bridges (EA - B 22a),

Tentative Specifications for Tin-Bronze and Leaded Tin-Bronze Sand Castings (EA - B 143a),

Tentative Specifications for High-Leaded Tin-Bronze Sand Castings (EA - B 144a),

Tentative Specifications for Leaded Red Brass and Leaded Semi Red Brass Sand Castings (EA - B 145a), and

Tentative Specifications for Leaded Yellow Brass Sand Castings for General Purposes (EA - 146a).

All of these recommendations were accepted by Committee E-10 on December 27, 1943, with the exception of EA - B 16 which was accepted on March 21, 1944. The former were published in ASTM Bulletin, No. 126, January, 1944, p. 46, and the latter in ASTM Bulletin, No. 127, March, 1944, p. 56. They have been issued in the form of stickers for attachment to the specifications to which they apply.

On January 31, 1944, Committee E-10 accepted[1] new Tentative Specifications for Copper Bus Bars, Rods, and Shapes (B 187 - 44 T) and for Copper Bus Pipes and Tubes (B 188 - 44 T), submitted by Committee B-5, which are published in the 1944 Book of A.S.T.M. Standards, Part I.

Withdrawal of Emergency Alternate Provisions

Certain of the revisions being recommended in the standards and tentative standards include changes now published as emergency alternate provisions. For the most part these include references to

---

[1] In submitting these recommendations to Committee E-10 on Standards, Committee B-5 reported the following results of the letter ballot vote from a committee membership of 100: B 187, affirmative 34, negative 1, ballots marked "not voting" 27; B 188, affirmative 35, negative 0, ballots marked "not voting" 27.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. Revisions of Tentative Standards			
Spec. for Cartridge Brass Sheet, Strip, and Disks (B 19 - 42 T)	30	0	27
Spec. for Bronze Castings for Turntables and Movable Bridges and for Bearing and Expansion Plates of Fixed Bridges (B 22 - 42 T)	21	0	24
Spec. for Copper-Base Alloys in Ingot Form for Sand Castings (B 30 - 42 T)	40	1	23
Spec. for Brass Sheet and Strip (B 36 - 43 T)	32	0	25
Spec. for Leaded Brass Sheet and Strip (B 121 - 43 T)	32	0	25
Spec. for Copper-Base Alloy Forging Rods, Bars, and Shapes (B 124 - 42 T)	28	0	17
Spec. for Cartridge Brass Cartridge Case Cups (B 129 - 43 T)	23	0	22
Spec. for Gilding Metal Sheet and Strip (B 130 - 43 T)	31	0	26
Spec. for Gilding Metal Bullet Jacket Cups (B 131 - 43 T)	22	0	23
Spec. for Leaded High-Strength Yellow Brass (Manganese Bronze) Sand Castings (B 132 - 41 T)	30	0	15
Spec. for Copper Rods, Bars, and Shapes (B 133 - 42 T)	27	0	18
Spec. for Brass Wire (B 134 - 42 T)	28	0	17
Spec. for Phosphor Bronze Rods, Bars, and Shapes (B 139 - 42 T)	27	0	18
Spec. for Tin-Bronze and Leaded Tin-Bronze Sand Castings (B 143 - 42 T)	31	0	14
Spec. for High-Leaded Tin-Bronze Sand Castings (B 144)	30	0	15
Spec. for Leaded Red Brass and Leaded Semi Red Brass Sand Castings (B 145 - 42 T)	31	0	14
Spec. for Leaded Yellow Brass Sand Castings for General Purposes (B 146 - 42 T)	30	0	15
Spec. for High-Strength Yellow Brass and High-Strength Leaded Yellow Brass Sand Castings (B 147 - 42 T)	40	1	23
Spec. for Aluminum Bronze Sand Castings (B 148-42 T)	40	0	24
Spec. for Leaded Nickel-Brass and Nickel-Bronze Sand Castings (B 149 - 42 T)	38	0	26
Spec. for Aluminum Bronze Rods, Bars and Shapes (B 150 - 41 T)	24	0	21
Spec. for Copper-Nickel-Zinc Alloy Rod and Wire (B 151 - 42 T)	25	0	20
Spec. for Copper Sheet, Strip, and Plate (B 152 - 41 T)	32	0	25
Spec. for Phosphor Bronze Wire (B 159 - 43 T)	27	0	18
Spec. for Aluminum Bronze Sheet and Strip (B 169 - 42 T)	28	0	29
II. Revisions of Standards, Immediate Adoption			
Spec. for Free-Cutting Brass Rod for Use in Screw Machines (B 16 - 42; ASA H8-1942)	34	1	21
Spec. for Steam or Valve Bronze Castings (B 61 - 42)	28	0	17
Spec. for Composition Brass or Ounce Metal Castings (B 62)	29	0	16
II. Revisions of Standards, Immediate Adoption—*Cont.*			
Spec. for Bronze Castings in the Rough for Locomotive Wearing Parts (B 66 - 38)	21	0	24
Spec. for Car and Tender Journal Bearings, Lined (B 67 - 38)	15	0	30
Spec. for Copper-Silicon Alloy Sheet for General Purposes (B 97 - 41)	24	0	21
Spec. for Copper-Silicon Alloy Rods, Bars, and Shapes (B 98 - 42)	31	1	24
Spec. for Rolled Copper-Alloy Bearing and Expansion Plates for Bridge and Other Structural Uses (B 100 - 43)	20	0	25
Spec. for Phosphor Bronze Sheet and Strip (B 103 - 43)	25	0	20
III. Withdrawal of Standard			
Spec. for Castings of the Alloy: Copper 88 per cent, Tin 8 per cent, Zinc 4 per cent (B 60 - 41)	43	0	21

the Emergency Specifications for Fire-Refined Copper for Wrought Products and Alloys (ES - 7). In a few other cases the emergency provisions are no longer necessary. The committee accordingly recommends that concurrently with the approval of the recommendations affecting standards in this report the following emergency alternate provisions be withdrawn:

Emergency Alternate Provisions in Specifications for:

Cartridge Brass Sheet, Strip, and Disks (EA - B 19),
Brass Sheet and Strip (EA - B 36),
Rolled Copper-Alloy Bearing and Expansion Plates for Bridge and Other Structural Uses (EA - B 100), and
Phosphor Bronze Sheet and Strip (EA - B 103).
Leaded Brass Sheet and Strip (EA - B 121),
Copper-Base Alloy Forging Rods, Bars, and Shapes (EA - B 124),
Cartridge Brass Cartridge Case Cups (EA - B 129),
Gilding Metal Sheet and Strip (EA - B 130),
Gilding Metal Bullet Jacket Cups (EA - B 131),
Copper Rods, Bars, and Shapes (EA - B 133),
Brass Wire (EA - B 134),
Phosphor Bronze Rods, Bars, and Shapes (EA - B 139),

Copper-Nickel-Zinc Alloy Rod and Wire (EA – B 151),
Copper Sheet, Strip, and Plate (EA – B 152),
Phosphor Bronze Wire (EA – B 159), and
Aluminum Bronze Sheet and Strip (EA – B 169).
Copper-Base Alloys in Ingot Form for Sand Castings (EA – B 30),
Castings of the Alloy: Copper 88 per cent, Tin 8 per cent, Zinc 4 per cent (EA – B 60a),

The committee also recommends that upon approval of the recommended revisions in the specifications for copper-alloy ingots and castings, as listed in the Appendix, the following emergency alternate provisions be revised by deleting all of the alternate provisions with the exception of the alternate cast-to-size test bars:

Emergency Alternate Provisions in Specifications for:

Bronze Castings for Turntables and Movable Bridges and for Bearing and Expansion Plates of Fixed Bridges (EA – B 22a),
Steam or Valve Bronze Castings (EA – B 61),
Composition Brass or Ounce Metal Castings (EA – B 62a),
Tin-Bronze and Leaded Tin-Bronze Sand Castings (EA – B 143a),
High-Leaded Tin-Bronze Sand Castings (EA – B 144a),
Leaded Red Brass and Leaded Semi Red Brass Sand Castings (EA – B 145a), and
Leaded Yellow Brass Sand Castings for General Purposes (EA – B 146a).

RECOMMENDATIONS AFFECTING STANDARDS

The committee is recommending revisions in twenty-five tentative standards and revisions in nine standards for immediate adoption. The standards and tentative standards affected are listed in Table I and the revisions recommended are given in detail in the Appendix.

The recommendations in this report have been submitted to letter ballot of the committee which consists of 100 voting members, with the results shown in Table I.

ACTIVITIES OF SUBCOMMITTEES

Following is a report of the activities of the several subcommittees during the year. The approved recommendations of these committees affecting standards are given in the Appendix.

Subcommittee I on Copper-Zinc Sheet and Strip (G. H. Harnden, chairman).—Many recommendations were made for revisions in all the specifications under the jurisdiction of this subcommittee, as covered in the Appendix. It is also recommended that the Emergency Alternate Provisions EA – B 19, EA – B 36, EA – B 121, EA – B 129, EA – B 130 and EA – B 131 be withdrawn and that the provisions be incorporated in the respective specifications. At the March meeting it was decided in revising the Tentative Specifications for Leaded Brass Sheet and Strip (B 121 – 43 T) to use so far as possible the standard commercial leaded alloy composition ranges covered in Alloys-I of the Copper and Brass Research Association.

The letter ballot on the addition of a table of preferred thicknesses for uncoated metals as an appendix to the sheet and strip specifications received four negative votes. The subject is receiving further consideration.

Subcommittee II on Copper-Tin Sheet and Strip (H. V. Schlacks, chairman) recommended slight changes in the Standard Specifications for Rolled Copper-Alloy Bearing and Expansion Plates for Bridge and Other Structural Uses (B 100 – 43) and for Phosphor Bronze Sheet and Strip (B 103 – 43). It also voted to incorporate the emergency provisions referring to Emergency Specifications ES – 7 in these two specifications, withdrawing EA – B 100 and EA – B 103.

Subcommittee III on Copper-Nickel-Zinc Sheet and Strip (R. B. Hitchcock, chairman) held a meeting on March 1, 1944, at which several proposals were made for revision of the Tentative Specifications for Copper-Nickel-Zinc and Copper-Nickel Alloy Sheet and Strip (B 122 - 42 T). Tables of physical properties and tolerances are to be reviewed for early action by the subcommittee.

Subcommittee IV on Miscellaneous Copper-Base Sheet and Strip Alloys (R. J. Wheeler, chairman).—A special committee (Messrs. L. L. Wyman, G. R. Gohn, and C. H. Davis) was named to study the hydrogen embrittlement test for high-conductivity oxygen-free copper. Another special committee, (Messrs. G. H. Harnden, H. C. Ashley, R. B. Hitchcock, and C. H. Davis) was appointed to review the Tentative Specifications for Copper Sheet, Strip, and Plate (B 152 - 41 T) with the idea of writing a separate portion or specification to cover bars and plates. The recommendations with respect to the Standard Specifications for Copper-Silicon Alloy Sheet for General Purposes (B 97 - 41), Tentative Specifications for Copper Sheet, Strip, and Plate (B 152 - 41 T), and for Aluminum Bronze Sheet and Strip (B 169 - 42 T) appear in the Appendix. A joint meeting with Subcommittee V was held to review the criticisms of the three proposed specifications for beryllium copper.

Subcommittee V on Miscellaneous Copper-Base Wire and Rod Alloys (H. C. Ashley, chairman).—Recommendations with respect to the Standard Specifications for Free-Cutting Brass Rod for Use in Screw Machines (B 16 - 42), for Copper-Silicon Alloy Rods, Bars, and Shapes (B 98 - 42), and the Tentative Specifications for Brass Wire (B 134 - 42 T) appear in the Appendix. A special committee (Messrs. G. R. Gohn and R. J. Wheeler) was appointed to prepare physical property tables for straightened rod and wire for inclusion in the Tentative Specifications for Phosphor Bronze Rods, Bars, and Shapes (B 139 - 42 T) and for Phosphor Bronze Wire (B 159 - 43 T). Another special committee (Messrs. G. H. Harnden, G. R. Gohn, Alan Morris, and C. H. Davis) was named to prepare chemical requirement tables for the two grades of aluminum bronze rod which were approved by letter ballot vote for inclusion in the Tentative Specifications for Aluminum Bronze Rods, Bars, and Shapes (B 150 - 41 T).[2]

It was voted to withdraw Emergency Alternate Provisions EA - B 133, EA - B 134, EA - B 139, EA - B 151, and EA - B 159 and to incorporate the provisions in the respective specifications.

Subcommittee X on Copper-Base Alloys for Sand Castings (G. H. Clamer, chairman).—Detailed consideration at two meetings has been given by this subcommittee to extensive revisions of the castings and ingot specifications for the tin bronzes, bearing metals, yellow brasses, and manganese bronzes involving changes in the following specifications:

Standard Specifications for:

Steam or Valve Bronze Castings (B 61 - 42),
Composition Brass or Ounce Metal Castings (B 62 - 41),
Bronze Castings in the Rough for Locomotive Wearing Parts (B 66 - 38),

Tentative Specifications for:

Copper-Base Alloys in Ingot Form for Sand Castings (B 30 - 42 T),
Leaded High-Strength Yellow Brass (Manganese Bronze) Sand Castings (B 132 - 41 T),
Tin-Bronze and Leaded Tin-Bronze Sand Castings (B 143 - 42 T),
High-Leaded Tin-Bronze Sand Castings (B 144 - 42 T),
Leaded Red Brass and Leaded Semi Red Brass Sand Castings (B 145 - 42 T), and
Leaded Yellow Brass Sand Castings for General Purposes (B 146 - 42 T).

A number of changes in the casting specifications have been approved by letter ballot in the subcommittee and were recommended to Committee B-5 for action.

---

[2] See Editorial Note, p. 248.

The changes in the casting specifications bring them substantially in line with the standard alloy compositions sponsored by the Conservation Division of the War Production Board. The same compositions and physical properties, with a few minor exceptions, will now be standard for the Navy, Federal, S.A.E. and A.S.T.M. specifications and S.A.E. is also currently considering changes in the Aeronautical Materials Specifications to bring them more in line. All A.S.T.M. emergency alternate compositions applying to copper-alloy ingots and castings have been cancelled, except that the casting specifications will still carry emergency alternate requirements for cast-to-size test bars as recently issued.

The most far-reaching change involved the addition of sand cast test bar requirements in the ingot Specifications B 30. At the same time the requirements for lot size and sampling in Specifications B 30 were revised.

The requirement for "other impurities" has been deleted from all casting specifications which have values given for tensile requirements. The number of significant figures for main constituents has been reduced in all specifications by eliminating the zero in the second decimal place. Alloy 3-B is designated as an Emergency Alternate composition for class C of Specifications B 22.

Revision of the Tentative Specifications for Aluminum-Bronze Sand Castings (B 148 - 42 T) is recommended. A recommendation for the development of an exact procedure for making test bars has been approved by letter ballot vote, but no steps to implement this latter item have yet been taken.

A special subcommittee (Messrs. L. M. Long, J. F. Ednie, William Romanoff, and C. S. Cole) has reviewed, at the request of the appropriate S.A.E. Division the hardness requirements in the A.M.S. copper-base alloy casting specifications.

A special subcommittee (Messrs. J. W. Bolton, J. J. Curran, and J. J. Kanter) is considering the revision of Specifications B 61 and B 62. Consideration is also being given to the need for retaining the class B Alloy in Specifications B 132.

Subcommittee XI on Methods of Test for Copper and Copper Alloys (A. J. Phillips, chairman) has held no meetings but its chairman has participated in several committee discussions relative to methods of test.

Subcommittee XII on Publication of General Information (C. S. Cole, chairman) has assisted the Society of Automotive Engineers in the preparation of a new definition of brass and bronze for inclusion in the S.A.E. Handbook and the chairman has been of assistance in matters of general policy on publications.

Subcommittee XIII on Tolerances (J. E. McGraw, chairman) prepared a table of preferred thicknesses for uncoated metals and alloys that might be used by the subcommittees having jurisdiction over sheet and strip materials. It was suggested that the table be included as an appendix to the sheet and strip specifications. Agreement on this proposal was not reached by the three subcommittees, however. The results of the letter ballot vote were reported to the main committee and this matter is still under consideration.

Several recommendations on tolerances have been referred to interested subcommittees. In most instances favorable action has been taken on these recommendations and they appear in the Appendix. The tolerances in twenty-four specifications were critically reviewed.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, G. H. Harnden.
Vice-Chairman, C. S. Cole.
Vice-Chairman, J. J. Kanter.
Secretary, V. P. Weaver.

This report has been submitted to letter ballot of the committee which consists of 100 voting members; 45 members returned their ballots, of whom 33 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the committee,

C. H. GREENALL,
Chairman.

C. H. DAVIS,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee B-5 presented to the Society through Committee E-10 on Standards the following recommendations in line with the actions set forth in this report:

Withdrawal of Emergency Alternate Provisions in Specifications for:

Cartridge Brass Sheet, Strip, and Disks (EA - B 19),
Copper-Base Alloys in Ingot Form for Sand Castings (EA - B 30),
Brass Sheet and Strip (EA - B 36),
Rolled Copper-Alloy Bearing and Expansion Plates for Bridge and Other Structural Uses (EA - B 100),
Phosphor Bronze Sheet and Strip (EA - B 103),
Leaded Brass Sheet and Strip (EA - B 121),
Copper-Base Alloy Forging Rods, Bars, and Shapes (EA - B 124),
Cartridge Brass Cartridge Case Cups (EA - B 129),
Gilding Metal Sheet and Strip (EA - B 130),
Gilding Metal Bullet Jacket Cups (EA - B 131),
Copper Rods, Bars, and Shapes (EA - B 133),
Brass Wire (EA - B 134),
Phosphor Bronze Rods, Bars, and Shapes (EA - B 139),
Copper-Nickel-Zinc Alloy Rod and Wire (EA - B 151),
Copper Sheet, Strip, and Plate (EA - B 152),
Phosphor Bronze Wire (EA - B 159),
Aluminum Bronze Sheet and Strip (EA - B 169), and
Castings of the Alloy: Copper 88 per cent, Tin 8 per cent, Zinc 4 per cent (EA - B 60a), since Standard B 60 - 41 was withdrawn at the Annual Meeting.

Revision of Emergency Alternate Provisions in Specifications for:

Bronze Castings for Turntables and Movable Bridges and for Bearing and Expansion Plates of Fixed Bridges (EA - B 22a),
Steam or Valve Bronze Castings (EA - B 61),
Composition Brass or Ounce Metal Castings (EA - B 62a),
Tin-Bronze and Leaded Tin-Bronze Sand Castings (EA - B 143a),
High-Leaded Tin-Bronze Sand Castings (EA - B 144a),
Leaded Red Brass and Leaded Semi Red Brass Sand Castings (EA - B 145a), and
Leaded Yellow Brass Sand Castings for General Purposes (EA - B 146a).

These recommendations were accepted by Committee E-10 on August 28, 1944, and the revised emergency alternate provisions appear in the 1944 Book of A.S.T.M. Standards, Part I.

On November 22, 1944, the Standards Committee accepted the following recommendations of Committee B-5:

Revision of Tentative Specifications for:

Cartridge Brass Sheet, Strip, and Disks (B 19 - 44 T),
Brass Sheet and Strip (B 36 - 44 T),
Leaded Brass Sheet and Strip (B 121 - 44 T),
Gilding Metal Sheet and Strip (B 130 - 44 T),
Copper Sheet, Strip, and Plate (B 152 - 44 T),
Aluminum Bronze Sheet and Strip (B 169 - 44 T),
Naval Brass Rods, Bars, and Shapes (B 21 - 42 T),
Copper Rods, Bars, and Shapes (B 133 - 44 T),

Brass Wire (B 134 - 44 T),
Phosphor Bronze Rods, Bars, and Shapes (B 139 - 44 T),
Aluminum Bronze Rods, Bars, and Shapes (B 150 - 44 T),
Copper-Nickel-Zinc Alloy Rod and Wire (B 151 - 44 T),
Phosphor Bronze Wire (B 159 - 44 T),
Copper Bus Bars, Rods, and Shapes (B 187 - 44 T),
Copper Bus Pipes and Tubes (B 188 - 44 T),

Tentative Revision of Standard Specifications for:

Manganese Bronze Rods, Bars, and Shapes (B 138 - 43), and
Leaded Red Brass (Hardware Bronze) Rods, Bars, and Shapes (B 140 - 43).

The revised tentative specifications and tentative revisions also appear in the 1944 Book of A.S.T.M. Standards, Part I.

APPENDIX

RECOMMENDATIONS AFFECTING STANDARDS FOR COPPER AND COPPER ALLOYS, CAST AND WROUGHT

In this Appendix are given the recommendations affecting certain standards and tentative standards covering copper and copper alloys which are referred to earlier in this report. The standards and tentative standards appear in their present form in the 1942 Book of A.S.T.M. Standards, Part I, and the 1943 Supplement, Part I.

REVISIONS OF TENTATIVE STANDARDS

The committee recommends that the following 25 tentative specifications be revised as indicated below and continued as tentative:

Tentative Specifications for Cartridge Brass Sheet, Strip, and Disks (B 19 - 42 T):

Title.—Change the title to read as follows: "Cartridge Brass Sheet, Strip, Plate, Bar, and Disks."

Section 3 (a).—Revise this section by including a reference to the Emergency Specifications for Fire-Refined Copper for Wrought Products and Alloys (A.S.T.M. Designation: ES-7), thereby eliminating the need of the Emergency Alternate Provisions EA-B 19 which are to be withdrawn.

Section 3 (b).—Insert the words "clean scrap" between the words "or" and "composed" in line 4.

Section 4.—Change the requirement for lead content from "0.050" to read "0.070" max., per cent.

NOTE 2.—Change to read as follows: "The presence of bismuth or mercury is objectionable in cartridge brass, and if found by the purchaser in excess of 0.006 per cent for bismuth and 0.0001 per cent for mercury, may constitute cause for rejection of the lot."

Section 15.—Add to the present table the width tolerances for square-sheared metal and sawed metal shown in the accompanying Table I.

Section 17.—Replace the present table of straightness tolerances by the accompanying Table II.

Section 18 (a).—Reword the first sentence of this paragraph to read as follows: "The material shall be furnished in flat, straight lengths unless rolls are specified."

Section 18 (b).—Replace present table of length tolerances by the accompanying Table III.

Section 18 (c).—Change to read: "When special lengths are required, they shall be specified in the order." Unilateral plus tolerances from the nominal length specified shall be permitted as prescribed in the accompanying Table IV.

Tentative Specifications for Bronze Castings for Turntables and Movable Bridges and for Bearing and Expansion Plates of Fixed Bridges (B 22 - 42 T):

Section 2 (a).—Revise this section by including a reference to Emergency Specifications ES-7, thereby eliminating the need of the Emergency Alternate Provisions EA-B 22a which are to be withdrawn.

TABLE I.—WIDTH TOLERANCES.

SQUARE SHEARED METAL
(All Lengths up to 120 in., incl.)

Width, in.	Width Tolerances,[a] plus and minus, in.		
	1/16 in. and under in Thickness	Over 1/16 to 1/8 in., incl., in Thickness	Over 1/8 in. in Thickness
20 and under	1/32	3/64	1/16
Over 20 to 36, incl.	3/64	3/64	1/16
Over 36 to 60, incl.	1/16	1/16	1/16

SAWED METAL
(All Widths up to 112 in., incl.)

Length, in.	Width Tolerances,[a] plus and minus, in.	
	1½ in. and under in Thickness	Over 1½ to 2¼ in., incl., in Thickness
120 and under	1/32	1/16
Over 120 to 200, incl.	1/16	1/16

[a] When tolerances are specified as all plus or all minus, double the above values.

Emergency Alternate Provisions.—In EA-B 22a revise the chemical and physical requirements of class C bronze castings to read as follows:

	Min.	Max.
Copper, per cent	**81.0**	**85.0**
Tin, per cent	**6.25**	**7.5**
Lead, per cent	**6.0**	**8.0**
Zinc, per cent	2.0	4.0
Nickel, per cent	...	0.50
Iron, per cent	...	0.20
Antimony, per cent	...	0.35
Phosphorus, per cent	...	0.15[a]
Tensile strength, min., psi.	30 000	
Yield strength, min., psi.	14 000	
Elongation, in 2 in., min., per cent	12	

[a] This value to be 0.50 max., per cent in permanent mold castings.

NOTE.—Analysis shall regularly be made only for the elements designated in **boldface type.** However, the presence of the other named elements outside of the limits specified in this table shall constitute cause for rejection of the castings.

Tentative Specifications for Copper-Base Alloys in Ingot Form for Sand Castings (B 30 – 42 T):

The proposed revision of these specifications includes changes in the chemical requirements for copper-base alloys in ingot form for sand casting, changes in sampling and the addition of tensile requirements for these alloys. The revised specifications are appended hereto.[1]

Tentative Specifications for Brass Sheet and Strip (B 36 – 43 T):

Section 3 (a).—Revise this section by including a reference to Emergency Specifications ES-7, thereby eliminating the need of the Emergency Alternate Provisions EA-B 36 which are to be withdrawn.

Section 3 (b).—Insert the words "clean scrap" between the words "or" and "composed" in line 4.

TABLE II.—STRAIGHTNESS TOLERANCES, IN.
Maximum Edgewise Curvature (depth (height) of arc) in any 72 in. Portion of the Total Length

SLIT METAL AND SLIT METAL WITH ROLLED EDGES

Width, in.	As Slit	With Rolled Edges or as Straightened
	Shipped in Rolls	Shipped Flat or in Rolls
½ and under	3	½
Over ½ to 1, incl.	1¼	½
Over 1 to 2, incl.	¾	½
Over 2 to 5, incl.	⅝	½
Over 5	½	½

SQUARE SHEARED METAL
(Not applicable to metal over 120 in. in length)

Thickness, in.	Straightness Tolerances, in.	
	Up to 10 in., incl. in Width	Over 10 in. in Width
⅛ and under	1/16	1/32
Over ⅛ to 3/16, incl.	⅛	3/64
Over 3/16	⅛	1/16

SAWED METAL
(Not applicable to metal over 144 in. in length)

Width, in.	Straightness Tolerances, in.
3 and under	1/16
Over 3	3/64

Section 4.—For alloy No. 4, change the requirements for copper from "79.0 to 81.0" to read "78.5 to 81.5" per cent.

Section 12 (a).—Change to read as follows: "12. (a) Tension tests shall be made on each lot of 5000 lb. or fraction thereof. The test specimens shall be taken parallel to the direction of rolling in such numbers and from such locations in each lot of material under test as to be representative of the quality, and not less than three specimens shall be considered representative of each lot or fraction thereof."

---

[1] These revised specifications were accepted by the Society and appear in the 1944 Book of A.S.T.M. Standards, Part I.

Section 12 (b).—Insert the word "three" before the words "representative specimens" in the last line.

Table IV.—In line 12, change the value "0.205" to read "0.187" and delete lines 13 to 18, inclusive.

TABLE III.—LENGTH TOLERANCES.

Stock Length or Mill Length, ft.	Indicated Lengths by Weight, min., per cent	Length of Shortest Piece, min., ft.	Indicated Shortest Length by Weight, max., per cent
10 and 12	60	4	10
8	70	3	10
6	80	2	10

TABLE IV.—LENGTH TOLERANCES.

Specific Length, ft.	Tolerances	
	Automatic Machine Cut, in.	Resquared Metal, or Square Sheared Metal, in.
Up to 10, incl.	+¼	+⅛
Over 10 to 20, incl.	+½	...

Tentative Specifications for Leaded Brass Sheet and Strip (B 121 – 43 T):

Section 3 (a).—Revise this section by including a reference to Emergency Specifications ES-7, thereby eliminating the need of the Emergency Alternate Provisions EA-B 121 which are to be withdrawn.

Section 3 (b).—Insert the words "clean scrap" between the words "or" and "composed" in line 4.

Section 4.—For alloy No. 2, change the requirements for copper from "63.00 to to 67.00" to read "62.5 to 66.5" per cent and the requirements for lead from "0.20 to 0.70" to read "0.30 to 0.70" per cent.

For alloy No. 3, change the requirements for copper from "63.00 to 67.00" to read "62.5 to 66.5" per cent and the requirements for lead range from "0.70 to 1.10" to read "0.75 to 1.25" per cent.

For alloy No. 4 change the requirements for copper from "61.00 to 64.00" to read "60.5 to 64.5" per cent and the requirements for lead from "1.25 to 2.00" to read "1.25 to 2.25" per cent.

Delete alloys Nos. 5 and 7 from the table.

For alloy No. 6, change the requirements for copper from "62.0 to 65.5" to read "60.0 to 64.0" per cent.

Add a note to the table of chemical requirements to read as follows: "NOTE.—Alloy No. 7 has been discontinued and alloy No. 5 has been combined with alloy No. 4."

Table I.—Reword footnote *c* to read as follows: "Spring and extra spring temper are generally furnished only in alloy No. 4 (63 per cent copper, 35 per cent zinc)."

Section 12 (a).—Reword to read the same as recommended above for Section 12 (*a*) in Specifications B 36.

Table IV.—Make the same changes as recommended above for Table IV in Specifications B 36.

Tentative Specifications for Copper-Base Alloy Forging Rods, Bars, and Shapes (B 124 – 42 T):

Section 3 (a).—Revise this section by including a reference to Emergency Specifications ES-7, thereby eliminating the need of the Emergency Alternate Provisions EA-B 124 which are to be withdrawn.

Tentative Specifications for Cartridge Brass Cartridge Case Cups (B 129 – 43 T):

Section 3 (a).—Revise this section by including a reference to Emergency Specifications ES-7, thereby eliminating the need of the Emergency Alternate Provisions EA-B 129 which are to be withdrawn.

Section 3 (b).—Insert the words "clean scrap" between the words "or" and "composed" in line 4.

Tentative Specifications for Gilding Metal Sheet and Strip (B 130 – 43 T):

Title.—Change the title to read: "Tentative Specifications for Gilding Metal Strip."

Section 3(a).—Revise this section by including a reference to Emergency Specifications ES-7, thereby eliminating the need of the Emergency Alternate Provisions EA-B 130 which are to be withdrawn.

Section 3(b).—Insert the words "clean scrap" between the words "or" and "composed" in line 4.

Section 4.—Change the requirement for copper from "89.00 to 91.00" to read "89.00 to 92.00" per cent.

Section 6.—Reword to read the same as recommended above for Section 12(*a*) in Specifications B 36, and renumber as Paragraph (*a*), adding a new Paragraph (*b*) to read as follows: "(*b*) The number of hardness tests shall be not less than three on each of the three representative specimens."

Table IV.—In line 12, change the value "0.205" to read "0.187" and delete the last two lines of this table.

Tentative Specifications for Gilding Metal Bullet Jacket Cups (B 131 – 43 T):

Section 3(a).—Revise this section by including a reference to Emergency Specifications ES-7, thereby eliminating the need of the Emergency Alternate Provisions EA-B 131 which are to be withdrawn.

Tentative Specifications for Leaded High-Strength Yellow Brass (Manganese Bronze) Sand Castings (B 132 – 41 T):

Section 1 (b).—Add the following note at the end of this paragraph: "NOTE.—These specifications cover the technical requirements for copper-base alloy castings and are not intended for use for the corresponding alloys in ingot form which are specified in the Tentative Specifications for Copper-Base Alloys in Ingot Form for Sand Castings (A.S.T.M. Designation: B 30)."

Section 4 (a).—Change the requirement for minimum elongation in 2 in. in class A from "20" to "15.0" per cent and for class B from "12" to "15" per cent.

Section 7 (a).—Change the requirement for copper in class B from "58 to 64" to read "55 to 60" per cent.

Change the chemical requirements for class A where necessary, to agree with the following:

	Min.	Max.
Copper, per cent	**56.0**	**62.0**
Tin, per cent	...	1.5
Lead, per cent	**0.5**	**1.5**
Zinc, per cent	remainder	
Iron, per cent	...	2.0
Aluminum, per cent	...	1.5
Manganese, per cent	...	1.5

NOTE.—Analysis shall regularly be made only for the elements designated in **boldface type.** However, the presence of the other named elements outside of the limits specified in this table shall constitute cause for rejection of the castings.

Tentative Specifications for Copper Rods, Bars, and Shapes (B 133 – 42 T):

Section 3 (a).—Revise this section by including a reference to Emergency Specifications ES-7, thereby eliminating the need of the Emergency Alternate Provisions EA-B 133 which are to be withdrawn.

Section 5 (c).—Insert the words "if

TABLE V.

	1A		1B		2A		2B	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Copper, per cent	**86.0**	**89.0**	**86.0**	**89.0**	**86.0**	**90.0**	**85.0**	**89.0**
Tin, per cent	**9.0**	**11.0**	**7.5**	**9.0**	**5.5**	**6.5**	**7.5**	**9.0**
Lead, per cent	...	**0.30**	...	**0.30**	**1.0**	**2.0**	...	**1.0**
Zinc, per cent	1.0	3.0	3.0	5.0	3.0	5.0	3.0	5.0
Nickel, per cent	...	**1.0**	...	**1.0**	...	**1.0**	...	**1.0**
Iron, per cent	...	0.15	...	0.15	...	0.25	...	0.25
Phosphorus, per cent	...	0.05	...	0.05	...	0.05	...	0.05
Tensile strength, min., psi	40 000		40 000		34 000		36 000	
Yield strength, min., psi	18 000		18 000		16 000		16 000	
Elongation, in 2 in., min., per cent	20		20		22		18	

NOTE.—Analysis shall regularly be made only for the elements designated in **boldface type.** However, the presence of the other named elements outside of the limits specified in this table shall constitute cause for rejection of the castings.

TABLE VI.

	3A		3B		3C		3D		3E	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Copper, per cent	**78.0**	**82.0**	**81.0**	**85.0**	**83.0**	**86.0**	**75.0**	**79.0**	**68.5**	**73.5**
Tin, per cent	**9.0**	**11.0**	**6.25**	**7.5**	**4.5**	**6.0**	**6.25**	**7.5**	**4.5**	**6.0**
Lead, per cent	**8.0**	**11.0**	**6.0**	**8.0**	**8.0**	**10.0**	**13.0**	**16.0**	**22.0**	**25.0**
Zinc, per cent	...	0.75	2.0	4.0	...	2.0	...	0.75	...	0.50
Nickel, per cent	...	0.50	...	0.50	...	0.50	...	0.75	...	0.50
Iron, per cent	...	0.15[a]	...	0.20	...	0.20	...	0.15	...	0.15[a]
Antimony, per cent	...	0.55	...	0.35	...	0.30	...	0.75	...	0.75
Phosphorus, per cent	...	0.05	...	0.15[b]	...	...	...	0.05	...	0.05
Tensile strength, min., psi	25 000		30 000		25 000		25 000		21 000	
Yield strength, min., psi	12 000		14 000		12 000		14 000		...	
Elongation in 2 in., min., per cent	8		12		8		10		7	

[a] This value to be 0.35 max., per cent when used on steel backed bearings.

[b] This value to be 0.50 max., per cent in permanent mold castings.

NOTE.—Analysis shall regularly be made only for the elements designated in **boldface type.** However, the presence of the other named elements outside of the limits specified in this table shall constitute cause for rejection of the castings.

TABLE VII.

	4A		4B		5A		5B	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Copper, per cent	**84.0**[a]	**86.0**	**82.0**	**83.75**	**78.0**	**82.0**	**75.0**	**76.75**
Tin, per cent	**4.0**	**6.0**	**3.25**	**4.25**	**2.25**	**3.5**	**2.5**	**3.5**
Lead, per cent	**4.0**	**6.0**	**5.0**	**7.0**	**6.0**	**8.0**	**5.25**	**6.75**
Zinc, per cent	4.0	6.0	5.0	8.0	7.0	10.0	13.0	17.0
Nickel, per cent	...	**1.0**[a]	...	1.0	...	1.0	...	1.0
Iron, per cent	...	0.30	...	0.30	...	0.40	...	0.40
Phosphorus, per cent	...	0.05	...	0.03	...	0.02	...	0.02
Tensile strength, min., psi	30 000		29 000		29 000		25 000	
Yield strength, min., psi	14 000		12 000		13 000		12 000	
Elongation in 2 in., min., per cent	20		15		18		15	

[a] In determining copper minimum, copper may be calculated as copper plus nickel.

NOTE.—Analysis shall regularly be made only for the elements designated in **boldface type.** However, the presence of the other named elements outside of the limits specified in this table shall constitute cause for rejection of the castings.

TABLE VIII.

Classification	Aluminum Bronze			
Numerical Designation	9A	9B	9C	9D
Copper, min., per cent	**86.0**	**86.0**	**83.0**	**78.0**
Aluminum, per cent	**8.5 to 9.5**	**9.0 to 11.0**	**10.0 to 11.5**	**10.0 to 11.5**
Iron, per cent	**2.5 to 4.0**	**0.75 to 1.5**	**3.0 to 5.0**	**3.0 to 5.0**
Manganese, max., per cent		...	**0.5**	**3.5**
Nickel, per cent		...	**2.5** max.	**3.0 to 5.5**
Total named elements, min., per cent	**99.0**	**99.0**	**99.5**	**99.5**

NOTE.—Analysis shall regularly be made for all of the elements in this table.

required" directly after the word "shall" in line 3.

Tentative Specifications for Brass Wire (B 134 – 42 T):

Section 3 (a).—Revise this section by including a reference to Emergency Specifications ES-7, thereby eliminating the need of the Emergency Alternate Provisions EA-B 134 which are to be withdrawn.

Section 3 (b).—Insert the words "clean scrap" between the words "or" and "composed" in line 4.

Table I.—For alloy No. 4, change the requirements for copper from "79.0 to 81.0" to read "78.5 to 81.5" per cent.

For alloy No. 7, change the requirements for copper from "64.0 to 67.5" to read "63.0 to 67.5" per cent.

Tentative Specifications for Phosphor Bronze Rods, Bars, and Shapes (B 139 – 42 T):

Section 3 (a).—Revise this section by including a reference to Emergency Specifications ES-7, thereby eliminating the need of the Emergency Alternate Provisions EA-B 139 which are to be withdrawn.

Section 3 (b).—Insert the words "clean scrap" between the words "or" and "composed" in line 4.

Tentative Specifications for Tin-Bronze Sand Castings (B 143 – 42 T):

Section 1.—Add the same note at the end of the section as recommended above in Section 1 of Specifications B 132.

Section 8.—Change the heading of this section from "Pressure and Fracture Tests" to "Hydrostatic Test."

Emergency Alternate.—In the Emergency Alternate Provisions EA-B 143a delete all provisions except those for the cast to size test bar in Section 9 and Figs. 3 and 4.

Tables II and III.—Change the requirements as to chemical composition and tensile properties shown in Tables II and III, where necessary, to conform to the accompanying Table V.

Tentative Specifications for High-Leaded Tin-Bronze Sand Castings (B 144 – 42 T):

Section 1 (b).—Add the same note at the end of this paragraph as recommended above in Section 1 of Specifications B 132.

Tables II and III.—Change the requirements as to chemical composition and tensile properties shown in Tables II and III, where necessary, to conform to the accompanying Table VI.

Emergency Alternate.—In the Emergency Alternate Provisions EA-B144a delete all provisions except those for the cast to size test bar in Section 9 and Figs. 3 and 4.

Tentative Specifications for Leaded Red Brass and Leaded Semi Red Brass Sand Castings (B 145 – 42 T):

Section 1.—Add the same note at the end of this section as recommended above in Section 1 of Specifications B 132.

Tables II and III.—Change the requirements as to chemical composition and tensile properties shown in Tables II and III, where necessary, to conform to the accompanying Table VII.

Emergency Alternate.—In the Emergency Alternate Provisions EA-B 145a delete all provisions except those for the cast to size test bar in Section 9 and Figs. 3 and 4.

Tentative Specifications for Leaded Yellow Brass Sand Castings for General Purposes (B 146 – 42 T):

Section 1.—Add the same note at the end of this section as recommended above in Section 1 of Specifications B 132.

Tables II and III.—Change the requirements as to chemical composition and tensile properties shown in Tables

II and III, where necessary, to conform to the accompanying Table IX.

Emergency Alternate.—In the Emergency Alternate Provisions EA-B 146a delete all provisions except those for the cast to size test bar in Section 9 and Figs. 3 and 4.

Tentative Specifications for High-Strength Yellow Brass and High-Strength Leaded Yellow Brass Sand Castings (B 147 – 42 T):

Section 1.—Add the same note at the end of the section as recommended above in Section 1 of Specifications B 132.

Tables II and III.—Change the requirements as to chemical composition and tensile properties shown in Tables II and III, where necessary, to conform to the accompanying Table X.

Tentative Specifications for Aluminum-Bronze Sand Castings (B 148 – 42 T):

Table I.—Change the requirements as to chemical composition to read as shown in the accompanying Table VIII.

Table II.—Change the requirements as to tensile properties to read as follows:

Classification	Aluminum Bronze			
	AS CAST			
Numerical Designation	9A	9B	9C	9D
Tensile strength, min., psi	65 000	65 000	75 000	90 000
Yield strength,[a] min., psi	25 000	25 000	30 000	40 000
Elongation in 2 in., min., per cent	20	20	12	6
Brinell Hardness No.[b], min. (3000 kg. load)	110	110	150	190
	HEAT TREATED			
Numerical Designation		9B-HT	9C-HT	9D-HT
Tensile strength, min., psi	....	80 000	90 000	110 000
Yield strength,[a] min., psi	....	40 000	45 000	60 000
Elongation in 2 in., min., per cent	....	12	6	5
Brinell Hardness No.[b] (3000 kg. load)	....	160	190	200

[a] Yield strength shall be determined as the stress producing an elongation under load of 0.5 per cent, that is, 0.01 in. in a gage length of 2 in.

[b] For information only. See Section 8.

Tentative Specifications for Leaded Nickel-Brass (Leaded Nickel-Silver) and Leaded Nickel-Bronze (Leaded Nickel-Silver) Sand Castings (B 149 – 42 T):

Table II.—Omit the requirements for "Total other constituents;" delete all requirements for alloy 10 B; change zinc to read "remainder" in alloys 11 A and 11 B; change iron content from "1.00" to read "1.5" max. in alloys 11 A and 11 B.

Tentative Specifications for Aluminum Bronze Rods, Bars, and Shapes (B 150 – 41 T):

Table I.—Add in parentheses after the title of the present table the words (Type I) and add the following to Table I:

TENSILE REQUIREMENTS (TYPE II).

Diameter or Thickness, in.	Tensile Strength, min., psi.	Yield Strength,[a] min., psi.	Elongation in 2 in., min., per cent
Rounds Only:			
0.500 to 1.00, incl.	100 000	50 000	10
Over 1.000 to 2.000, incl.	90 000	45 000	12
Over 2.000 to 4.000, incl.	85 000	42 500	15

[a] = 0.50 per cent extension.

Tentative Specifications for Copper-Nickel-Zinc Alloy Rod and Wire (B 151 – 42 T):

Section 3 (a).—Revise this section by including a reference to Emergency Specifications ES-7, thereby eliminating the need of the Emergency Alternate Provisions EA-B 151 which are to be withdrawn.

Section 3 (b).—Insert the words "clean scrap" between the words "or" and "composed" in line 4.

Tentative Specifications for Copper Sheet, Strip, and Plate (B 152 – 41 T):

Section 3 (a).—Revise this section by including a reference to Emergency Specifications ES-7, thereby eliminating the need of the Emergency Alternate Provisions EA-B 152 which are to be withdrawn.

Section 21.—Change the first sentence to read as follows: "The copper shall be furnished in flat, straight lengths unless rolls are specified." When special lengths are required, they shall be specified in the order. Unilateral plus tolerances from the nominal length specified shall be permitted as prescribed in the accompanying Table IV.

TABLE IX.

	6A		6B		6C	
	Min.	Max.	Min.	Max.	Min.	Max.
Copper, per cent	**70.0**	**74.0**	**65.0**	**70.0**	**60.0**	**65.0**
Tin, per cent	**0.75**	**2.0**	...	**1.5**	**0.5**	**1.5**
Lead, per cent	**1.5**	**3.5**	**1.5**	**3.0**	**0.75**	**1.5**
Zinc, per cent	remainder		remainder		remainder	
Iron, max., per cent	...	0.60	...	0.75	...	0.75
Aluminum, max., per cent	...	...	...	0.30	...	**0.50**
Tensile strength, min., psi	35 000		30 000		40 000	
Yield strength, min., psi	12 000		11 000		14 000	
Elongation in 2 in., min., per cent	25		20		15	

NOTE.—Analysis shall regularly be made only for the elements designated in **boldface type.** However, the presence of the other named elements outside of the limits specified in this table shall constitute cause for rejection of the castings.

TABLE X.

	7A		8A		8B		8C	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Copper, per cent	**56.0**	**62.0**	**55.0**	**60.0**	**60.0**	**68.0**	**60.0**	**68.0**
Tin, max., per cent	...	1.5	...	1.0	...	0.5	...	0.5
Lead, max., per cent	**0.5**	**1.5**	...	**0.40**	...	**0.20**	...	**0.20**
Zinc, per cent	remainder		remainder		remainder		remainder	
Nickel, max., per cent	...	...	...	0.50	...	...	...	...
Iron, per cent	...	**2.0**	**0.40**	**2.0**	**2.0**	**4.0**	**2.0**	**4.0**
Aluminum, per cent	...	**1.5**	**0.50**	**1.5**	**3.0**	**7.5**	**3.0**	**7.5**
Manganese, per cent	...	**1.5**	...	**1.5**	**2.5**	**5.0**	**2.5**	**5.0**
Tensile strength, min., psi	60 000		65 000		90 000		110 000	
Yield strength, min., psi	20 000		25 000		45 000		60 000	
Elongation in 2 in., min., per cent	15		20		20		12	

NOTE.—Analysis shall regularly be made only for the elements designated in **boldface tvpe.** However, the presence of the other named elements outside of the limits specified in this table shall constitute cause for rejection of the castings.

Tentative Specifications for Phosphor Bronze Wire (B 159 – 43 T):

Section 3 (a).—Revise this section by including a reference to Emergency Specifications ES-7, thereby eliminating the need of the Emergency Alternate Provisions EA-B 159 which are to be withdrawn.

Tentative Specifications for Aluminum Bronze Sheet and Strip (B 169 – 42 T):

Section 3 (a).—Revise this section by including a reference to Emergency Specifications ES-7, thereby eliminating the need of the Emergency Alternate Provisions EA-B 169 which are to be withdrawn.

Section 12.—Replace present table by the accompanying Table II.

Section 13.—Change first sentence to read as follows: "The material shall be finished in flat, straight lengths unless rolls are specified." When special lengths are required, they shall be specified in the order. Unilateral plus tolerances from the nominal length specified shall be permitted as prescribed in the accompanying Table IV.

REVISION OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends for immediate adoption, revisions in 9 specifications, as indicated below, and accordingly asks for a nine-tenths affirmative vote at the Annual Meeting in order that these modifications may be referred to letter ballot of the Society.

Standard Specifications for Free-Cutting Brass Rod for Use in Screw Machines (B 16 - 42):

Section 11.—Omit the table in this section and add the tolerances as prescribed in the accompanying Tables XI, and XII.

TABLE XI.—LENGTH TOLERANCES.

Lengths	Length Tolerances, plus, in.
Specific Lengths	$\frac{3}{8}$
Stock Lengths	1
Random Lengths	none applicable

TABLE XII.—DIAMETER TOLERANCES.

Diameter or Distance Between Parallel Surfaces, in.	Tolerances, plus and minus,[a] in.	
	Round	Hexagon Octagon
Up to 0.150, incl.	0.0013	0.0025
Over 0.150 to 0 500, incl.	0.0015	0.003
Over 0.500 to 1.00, incl.	0.002	0.004
Over 1.00 to 2 50 incl.	0.0025	0.005
Over 2.50	15 per cent[b]	30 per cent[b]

[a] When tolerances are specified as all plus or all minus, double the above values.

[b] Expressed to the nearest 0.001 in.

Standard Specifications for Steam or Valve Bronze Castings (B 61 - 42):

Section 1.—Add the same note at the end of this paragraph as recommended above in Section 1 of Specifications B 132.

Section 4.—Change the chemical requirements, where necessary, to agree with the following:

	Min.	Max.
Copper, per cent	**86.0**	**90.0**
Tin, per cent	**5.5**	**6.5**
Lead, per cent	**1.0**	**2.0**
Zinc, per cent	3.0	5.0
Nickel, per cent	...	**1.0**
Iron, per cent	...	0.25
Phosphorus, per cent	...	0.05

NOTE.—Analysis shall regularly be made only for the elements designated in **boldface type.** However, the presence of the other named elements outside of the limits specified in this table shall constitute cause for rejection of the castings.

Section 6 (b).—Renumber as Section 7 with heading "Hydrostatic Test," renumbering the following sections accordingly.

Standard Specifications for Composition Brass or Ounce Metal Castings (B 62 - 41):

Sections 1 and 6 (d).—Make the same changes as recommended above in Sections 1 and 6(*b*) of Specifications B 61.

TABLE XIII.

	Phosphor Bronze		Hard Bronze		Medium Bronze		Soft Bronze	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Copper, per cent	remainder		remainder		remainder		remainder	
Tin, per cent	**7**	**9**	**6**	**9**	**6**	**8**	**4**	**6**
Lead, per cent	**9**	**12**	**10**	**16**	**16**	**22**	**23**	**27**
Zinc, per cent	...	0.75	...	1.25	...	**1.25**	...	**1.25**
Nickel, per cent	...	**1.00**	...	0.50	...	...	...	...
Iron, per cent	...	0.15	...	0.20	...	...	...	...
Antimony, per cent	...	0.75	...	**0.75**	...	...	...	...
Phosphorus, per cent	**0.20**	**0.50**	...	0.05	...	...	...	...
Other impurities, max., per cent	...	0.50	...	0.35	...	0.75	...	0.75

NOTE.—Analysis shall regularly be made only for the elements designated in **boldface type.** However, the presence of the other named elements outside of the limits specified in this table shall constitute cause for rejection of the castings.

Section 4.—Change the chemical requirements, where necessary, to agree with the following:

	Min.	Max.
Copper, per cent	**84.0**[a]	**86.0**
Tin, per cent	**4.0**	**6.0**
Lead, per cent	**4.0**	**6.0**
Zinc, per cent	4.0	6.0
Nickel, per cent	...	**1.0**[a]
Iron, per cent	...	0.30
Phosphorus, per cent	...	0.05

NOTE.—Analysis shall regularly be made only for the elements designated in **boldface type.** However, the presence of the other named elements outside of the limits specified in this table shall constitute cause for rejection of the castings.

[a] In determining copper, minimum copper may be computed as copper plus nickel.

Standard Specifications for Bronze Castings in the Rough for Locomotive Wearing Parts (B 66 – 38):

Table I.—Change the requirements as to chemical composition shown in Table I, where necessary, to conform to the accompanying Table XIII.

Standard Specifications for Car and Tender Journal Bearings, Lined (B 67 – 38):

Section 3.—Change the requirements as to chemical composition of the backing, where necessary, to conform to the following:

	Backs	
	Min.	Max.
Copper, per cent	**65**	**75**
Tin, per cent	**4.5**	**6.5**
Lead, per cent	...	**24**
Zinc, per cent	...	3
Other impurities, max., per cent	...	1

NOTE.—Analysis shall regularly be made only for the elements designated in **boldface type.** However the presence of the other named elements outside of the limit specified in this table shall constitute cause for rejection of the castings.

Standard Specifications for Copper-Silicon Alloy Sheet for General Purposes (B 97 – 41):

Title.—Change the title to read as follows: "Standard Specifications for Copper-Silicon Alloy Sheet and Strip for General Purposes."

Section 12.—Replace the straightness tolerances in the present table by the accompanying Table II.

Section 13.—Change the first sentence to read as follows: "The material shall be furnished in flat, straight lengths, unless rolls are specified." Also add the length tolerances as shown in the accompanying Tables III and IV.

Standard Specifications for Copper-Silicon Alloy Rods, Bars, and Shapes (B 98 – 42):

Table II.—Revise the values for hard temper for types A, C, and D alloy rods, and shapes by adding the following:

HARD TEMPER, TYPES A, C, AND D ALLOY RODS, AND SHAPES.

Diameter or Distance Between Parallel Faces, in.	Tensile Strength, min., psi.	Yield Strength, min., psi.	Elongation in 2 in., min., per cent	Bend Test, angle of bend, deg.
Up to ¼, incl.	85 000	50 000	8	90
Over ¼ to ½, incl.	85 000	50 000	14	90

Standard Specifications for Rolled Copper-Alloy Bearing and Expansion Plates for Bridge and Other Structural Uses (B 100 – 43):

Section 3 (a).—Revise this section by including a reference to Emergency Specifications ES-7, thereby eliminating the need of the Emergency Alternate Provisions EA-B 100 which are to be withdrawn.

Standard Specifications for Phosphor Bronze Sheet and Strip (B 103 – 43):

Section 3 (a).—Revise this section by including a reference to Emergency Specifications ES-7, thereby eliminating the need of the Emergency Alternate Provisions EA-B 103 which are to be withdrawn.

Section 3 (b).—Insert the words "clean scrap" between the words "or" and "composed" in line 4.

Section 14.—Add, to Table IV the tolerances for sawed metal as shown in the accompanying Table II.

Section 16.—Change the first sentence to read "The material shall be furnished in flat, straight lengths, unless rolls are specified." Delete the third sentence. Replace the present table of straightness tolerances in Section 15 by the accompanying Table II.

Section 17.—Add the length tolerances as shown in the accompanying Tables III and IV.

REPORT OF COMMITTEE B-6
ON
DIE-CAST METALS AND ALLOYS

Committee B-6 on Die-Cast Metals and Alloys held two meetings during the year: one in Pittsburgh, Pa., on June 29, 1943, and one in Cincinnati, Ohio, on February 29, 1944, with an attendance of 40 and 34, respectively.

A balance of $2869.00 was reported by Society Headquarters in the fund of Committee B-6 as of December 31, 1943.

The special subcommittee charged with raising $2000 has completed its assignment and has been discharged. The American Die Casting Institute's donation of $1000 represented the manufacturers of die castings so no other solicitation was made of such concerns. From the remainder of the membership about 30 companies were invited to contribute to this fund of which six were approached for $100 each and the remainder for $50 each. An itemized list of the 27 contributors follows:

Aluminum Company of America	$100
Aluminum and Magnesium, Inc.	50
American Brass Co., The	100
American Die Casting Institute	1000
American Machine and Metals	25
American Smelting and Refining Co.	50
American Society for Metals	125
Apex Smelting Co.	100
Automatic Electric Co.	50
Bell Telephone Laboratories, Inc.	100
Briggs and Stratton Corp.	50
Chrysler Corp.	50
Dow Chemical Co.	100
Duquesne Smelting Co.	50
General Electric Co.	50
Gerity-Adrian Manufacturing Co.	50
International Harvester Co.	50
Kramer and Co.	50
National Cash Register Co.	50
National Lead Co.	50
National Smelting Co.	100
New Jersey Zinc Co. (of Pa.), The	100
St. Joseph Lead Co.	150
Sperry Gyroscope Co.	50
Titan Metal Manufacturing Co.	50
U. S. Smelting, Refining, and Mining Co.	50
Westinghouse Air Brake Co.	50
	$2800

At the present time the committee consists of 82 members, of whom 38 are classified as producers, 21 as consumers, and 23 as general interest members.

RECOMMENDATIONS ACCEPTED BY COMMITTEE E-10 ON STANDARDS

Subsequent to the 1943 Annual Meeting, Committee B-6 presented to the Society, through Committee E-10 on Standards, the following recommendations:

New Emergency Specifications for:

Special Quality, Magnesium-Base Alloy Die Castings (ES – 40),[1]

Revision of Emergency Specifications for:

Special Quality, Aluminum-Base Alloy Die Castings (ES – 29)[1], and

Revision of the Emergency Alternate Provisions in:

Standard Specifications for Zinc-Base Alloy Die Castings (EA – B 86).

Emergency Specifications ES - 40 and revised Emergency Specifications ES - 29 were accepted by Committee E-10 on May 18, 1944, and November 24, 1943, respectively, and are available as separate reprints. An editorial revision in Emergency Standards ES – 29 and ES – 40 changing all references to read "special quality die castings" was accepted by Committee E-10.

---

[1] 1944 Book of A.S.T.M. Standards, Part I.

The revised Emergency Alternate Provisions EA - B 86b were accepted by Committee E-10 on January 8, 1944, published in ASTM BULLETIN, No. 126, January 1944, p. 46, and have been issued in the form of a pink sticker for attachment to the standard. As indicated below, it is now recommended that these emergency provisions be withdrawn.

EMERGENCY ALTERNATE PROVISIONS

The committee recommends that Emergency Alternate Provisions EA - B 85a in the Standard Specifications for Aluminum-Base Alloy Die Castings (B 85 – 42) and the Emergency Alternate Provisions EA – B 86b in the Standard Specifications for Zinc-Base Alloy Die Castings (B 86 - 43) be discontinued.

I. REVISION OF TENTATIVE STANDARD

The committee recommends that the Tentative Specifications for Magnesium-Base Alloy Die Castings (B 94 - 40 T) be revised as follows and continued as tentative:

Section 1.—Change the scope to specify three alloys instead of two and designate the new alloy as alloy No. 13X.

Section 3.—In the table of requirements for chemical composition, add the following requirements for alloy No. 13X:

	Alloy No. 13X
Magnesium, per cent	remainder
Aluminum, per cent	8.3 to 9.7
Manganese, min., per cent	0.13
Zinc, per cent	0.4 to 1.0
Silicon, max., per cent	0.3
Copper, max., per cent	0.05
Nickel, max., per cent	0.002
Iron, max., per cent	0.004

Explanatory Notes.—In Note 1 add reference to the fact that the tensile strength, per cent elongation, and Charpy impact of alloy No. 13X are the same as those for alloy No. 13.

Add the following paragraph to Note 2: "Alloy No. 13X has a specific gravity of about 1.81. It has good casting characteristics and possesses unusually good resistance to salt water corrosion."

This recommendation has been submitted to letter ballot of the committee which consists of 82 members; 68 members returned their ballots, of whom 45 have voted affirmatively, 2 negatively, and 21 members marked their ballots "not voting."

II. ADOPTION OF TENTATIVE STANDARD AS STANDARD

The committee recommends that the Tentative Specifications for Lead- and Tin-Base Alloy Die-Castings (B 102 - 39 T) be approved for reference to letter ballot of the Society for adoption as standard.

This recommendation has been submitted to letter ballot of the committee which consists of 82 members; 67 members returned their ballots, of whom 35 have voted affirmatively, 0 negatively, and 32 members marked their ballots "not voting."

III. REVISION OF STANDARD AND REVERSION TO TENTATIVE

The committee recommends that the Standard Specifications for Aluminum-Base Alloy Die Castings (B 85 – 42) be revised as follows and reverted to tentative:

Section 1.—Revise second sentence to read: "Seven alloy compositions are specified, designated as alloys Nos. S4, S5, S9, SC2, SC5, SC6 and SC7."

Section 2.—Delete Paragraphs (*b*) and (*c*).

Section 6.—Designate the present section as Paragraph (*a*), and add the following as Paragraph (*b*): "When so specified by the purchaser, castings shall be produced by the cold-chamber process."

Table I.—Replace the present table and notes with the accompanying Table I:

TABLE I.—CHEMICAL REQUIREMENTS.[a]

Alloy[b,c]	Copper, per cent	Iron, max., per cent	Silicon, max., per cent	Manganese, max., per cent	Magnesium max., per cent	Zinc, max., per cent	Nickel, max., per cent	Tin, max., per cent	Other Constituents, max., (Total), per cent
S4	0.6 max.	2.0	4.5 to 6.0	0.3	0.1	0.5	0.5	0.1	0.2
S5	0.6 max.	2.0	11.0 to 13.0	0.3	0.1	0.5	0.5	0.1	0.2
S9	0.6 max.	1.3	11.0 to 13.0	0.3	0.1	0.5	0.5	0.1	0.2
SC2	3.0 to 4.0	2.0	4.5 to 5.5	0.5	0.1	1.0	0.5	0.3	0.5
SC5	3.0 to 4.0	1.3	4.5 to 5.5	0.5	0.1	0.6	0.5	0.3	0.5
SC6	3.0 to 4.0	1.3	7.5 to 9.5	0.5	0.1	0.6	0.5	0.3	0.5
SC7	3.0 to 4.0	2.0	7.5 to 9.5	0.5	0.1	1.0	0.5	0.3	0.5

[a] Analysis shall ordinarily be made only for the elements mentioned in this table. If, however, the presence of other elements is suspected, or indicated in the course of routine analysis, further analysis shall be made to determine that the total of these other elements does not exceed the amount given in the last column.

[b] Alloys S4, S5, SC2, and SC7 are suitable for the production of castings by either the gooseneck or the cold-chamber process. Castings of alloys S9, SC5, and SC6 may be made only in cold-chamber machines.

[c] Alloys S4, S5, SC2, SC5, SC6 and SC7 formerly were designated, respectively, as alloys IV, V, VII-A, VII-B, LXXIX-B and LXXIX-A.

Appendix.—Delete the word "Rockwell" from the fourth sentence and substitute the following table for the one now given:

Alloy	Tension Tests on Round Specimens		Charpy Impact on Square Specimens, ft-lb.
	Tensile Strength, psi.	Elongation in 2 in., per cent	
S4	30 000	5.0	4.5
S5	37 000	1.8	2.0
S9	35 000	3.5	...
SC2	38 000	2.5	2.5
SC5	35 000	3.0	3.0
SC6	41 000	3.0	3.5
SC7	43 000	2.0	3.2

This recommendation has been submitted to letter ballot of the committee which consists of 82 members; 76 members returned their ballots, of whom 52 have voted affirmatively, 1 negatively, and 23 members marked their ballots "not voting."

IV. TENTATIVE STANDARD CONTINUED AS TENTATIVE

The committee recommends that the Tentative Specifications for Copper-Base (Brass) Alloy Die Castings (B 176 - 42 T) be continued as tentative without revision.

This recommendation has been submitted to letter ballot of the committee which consists of 82 members; 68 members returned their ballots, of whom 38 have voted affirmatively, 0 negatively, and 30 members marked their ballots "not voting."

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Aluminum-Base Die Casting Alloys (J. J. Bowman, chairman, replacing E. E. Thum, resigned) prepared the revision in the Emergency Specifications for Special Quality Aluminum-Base Alloy Die Castings (ES - 29), referred to earlier in this report.

Two companies have produced test bars of alloy G2 (8 per cent magnesium, remainder aluminum) for salt spray and atmospheric exposure testing. It is planned to expose these bars in industrial and sea coast atmospheres in August of this year at which time exposure racks, from previous programs, will become available.

Plans for the casting of test bars of alloy SG2 (9.5 per cent silicon, 0.5 per cent magnesium, remainder aluminum) have not progressed as rapidly as desired. It is hoped that both alloy G2 and alloy SG2 will be ready for atmospheric exposure testing simultaneously.

Through a subgroup, the subcommittee is attempting to eliminate minor discrepancies and promote better agreement between the Government and A.S.T.M. specifications for aluminum die castings.

Subcommittee II on Zinc-Base Die-Casting Alloys (A. E. Weiss, chairman, replacing C. T. Prendergast, resigned) is preparing revisions in the Tentative Specifications for Special Grade Zinc-Base Alloy Die Castings (B 186 – 42 T) and recommends that Emergency Alternate Provisions EA – B 86b in the Standard Specifications for Zinc-Base Alloy Die Castings (B 86 – 43) be discontinued as mentioned earlier in this report.

Subcommittee IV on Physical Tests of Die Castings (R. L. Templin, chairman) discussed tension-impact testing and the development of standard test bar dies.

The discussions on tension-impact testing of die castings revealed that Government sponsored research on impact testing was being conducted at California Institute of Technology and at Watertown Arsenal. The results of these investigations are expected to be released eventually. In addition, the chairman will investigate the progress made on this problem by Committee E-1 on Methods of Testing.

The subcommittee discussed the desirability of undertaking the design of standard test bar dies for the production of test specimens. After examining many test bar die designs, it was apparent that the design for zinc alloys could not be used for aluminum, magnesium, or brass alloys. In fact there was evidence that it was impossible to adopt one standard die for the aluminum alloys alone. In view of this evidence it was decided to table this problem until the results are known of the work being done by a sub-subcommittee of Subcommittee I which is now engaged in a study of certain aluminum die-casting alloys as cast in the same die, with two gate sizes, by several different producers.

Subcommittee V on Exposure and Corrosion Tests (W. M. Peirce, chairman) has decided to recall all test specimens from the exposure locations which had been scheduled for testing during 1944. This includes (*1*) one zinc and nine aluminum alloys from six outdoor sites and one zinc and twelve aluminum alloys from four indoor sites after 15 years of exposure, (*2*) twenty round and four flat tension bars of each of three aluminum alloys from three outdoor locations after 10 years of exposure, and (*3*) three zinc and four magnesium alloys from ten sites after 5 years of exposure.

Volunteers, to assist with the testing of these specimens, are being solicited.

Subcommittee VII on Magnesium-Base Die-Casting Alloys (H. W. Schmidt, chairman, replacing J. A. Gann, resigned) prepared the Emergency Specifications for Special Quality, Magnesium-Base Alloy Die Castings (ES – 40) and recommended the revisions in the Tentative Specifications for Magnesium-Base Alloy Die Castings (B 94 – 40 T) covered earlier in this report.

Subcommittee VIII on Copper-Base (Brass) Die-Casting Alloys (J. C. Fox, chairman) decided to determine the mechanical properties and physical constants of the brass alloys listed in the Tentative Specifications for Copper-Base (Brass) Alloy Die Castings (B 176 – 42 T). For this purpose, test bars will be die cast by several producers from alloys both with the normal range of compositions as well as from alloys having the maximum and minimum impurity limits.

The subject of die steels for brass alloy die casting is under consideration. Before undertaking new experimental work, it was decided that the chairman should prepare a paper covering the work that has been done to date.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, J. R. Townsend.
Vice-Chairman, J. C. Fox.
Secretary, G. L. Werley.

This report has been submitted to letter ballot of the committee which consists of 82 members; 65 members returned their ballots, of whom 61 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the committee,

J. R. TOWNSEND,
Chairman.

G. L. WERLEY,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting Committee B-6 recommended to Committee E-10 on Standards that the following emergency alternate provisions be withdrawn:

Emergency Alternate Provisions in:

Standard Specifications for Aluminum-Base Alloy Die Castings (EA - B 85a), and

Standard Specifications for Zinc-Base Alloy Die Castings (EA - B 86b).

This recommendation was accepted by Committee E-10 on August 28, 1944.

REPORT OF COMMITTEE B-7

ON

LIGHT METALS AND ALLOYS, CAST AND WROUGHT

Committee B-7 on Light Metals and Alloys, Cast and Wrought, has held two meetings during the past year: in Pittsburgh, Pa., on June 30, 1943, and in Cincinnati, Ohio, on March 1, 1944. Several of the subcommittees also held meetings during this period.

A number of changes in the membership of Committee B-7 and its various subcommittees have been made during the year. The membership of the committee now totals 55, of whom 22 are classified as producers, 22 as consumers, and 11 as general interest members.

It is with regret that record is made of the resignation of J. A. Gann, vice-chairman of Committee B-7 and chairman of Subcommittee IV, as Mr. Gann has long been identified with the activities of Committee B-7. H. W. Schmidt, also of Dow Chemical Co., was appointed chairman of Subcommittee IV to replace Mr. Gann.

In general, the activities of Committee B-7 and its subcommittees during the year have been directed toward bringing the various specifications under its jurisdiction in line with present production practices. This work has been handicapped for several years, and is still handicapped to some extent, by the uncertainty with respect to the availability of certain materials and lack of data in connection with the effect of impurities in various alloys. The data presented by Walter Bonsack, a member of Committee B-7, in his two papers on "The Effects of Minor Alloying Elements on Aluminum Casting Alloys"[1] have been of material help in this problem.

The committee's activities in this connection are reflected in the various changes in specifications recommended in this report.

I. Revision of Tentative Standards

The committee recommends that the fourteen tentative specifications listed in Item I of Table I be revised as indicated in the Appendix and continued as tentative. These revisions are desired in order to bring the specifications in line with present commercial practices.

Code System for Designation of Magnesium Alloys.—The committee is also recommending the adoption of a code system for the designation of the magnesium-base alloys in the various magnesium specifications under its jurisdiction. This system was developed by Subcommittee VII following the system adopted in 1942 for the aluminum-base alloys. The basis of this code system is as follows:

> Letters will be used to designate the alloy constituents and numbers for the approximate composition. The alloy constituents present in the greatest amount will be shown first, and the minor constituents following in order of the amount present. The alloy constituents shall be designated by the following letters:

---

[1] ASTM Bulletins, No. 117, August, 1942, p. 54, and No. 124, October, 1943, p. 41.

A—aluminum
M—manganese[a]
S—silicon
Z—zinc
T—tin
D—cadmium
X—High Purity[b]

For the most part the letter designation is relatively simple. Only the major alloy constituents are considered. A number follows the letter to designate the approximate composition. Thus a binary alloy containing 4 per cent aluminum would be designated A4. Since all magnesium alloys contain manganese in a small but essential amount, this will be understood but will not be considered in the designation. An alloy containing 6 per cent aluminum and 3 per cent zinc would be designated AZ63. If any alloy constituent is present in less than 1 per cent or if no minimum amount is specified, it will be designated by a zero.

The system is very flexible and can be easily extended. The alloy designations assigned in accordance with this code to the present specifications for magnesium-base alloys are given in the Appendix in connection with the revisions in Specifications B 80, B 90, B 91, B 93, and B 107.

II. ADOPTION OF TENTATIVE STANDARD AS STANDARD

Suppliers of aluminum ingot as covered by the Tentative Specifications for Aluminum Ingots for Remelting (B 24 – 41 T) have been contacted for possible objections to the adoption of these specifications as standard. No objections have been recorded, and it is, therefore, recommended that the specifications be approved for reference to letter ballot of the Society for adoption as standard.

III. TENTATIVE STANDARDS CONTINUED AS TENTATIVE WITHOUT CHANGE

In accordance with the Regulations of the Society, the committee has reviewed those tentative standards which have stood for two years or more without revision and recommends that the following specifications and methods of test be continued as tentative without change:

Tentative Specifications for:

Aluminum for Use in Iron and Steel Manufacture (B 37 – 42 T),
Aluminum-Base Alloys in Ingot Form for Die Castings (B 125 – 42 T),

Tentative Methods of Test for:

Dielectric Strength of Anodized Aluminum (B 110 – 39 T),

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballot Marked "Not Voting"
Proposed Code System for Designation of Magnesium Base Alloys	27	0	4
I. REVISION OF TENTATIVE STANDARDS			
Spec. for Aluminum Sheet and Plate (B 25 – 43 T)	17	0	0
Spec. for Aluminum-Base Alloy Sand Castings (B 26 – 43 T)	20	1	10
Spec. for Aluminum-Alloy (Duralumin) Sheet and Plate (Aluminum-Copper-Magnesium-Manganese) (B 78 – 42 T)	18	0	13
Spec. for Aluminum-Manganese Alloy Sheet and Plate (B 79 – 43 T)	18	0	13
Spec. for Magnesium-Base Alloy Sand Castings (B 80 – 41 T)	27	0	8
Spec. for Aluminum-Alloy (Duralumin) Bars, Rods, Wire, and Shapes (Aluminum-Copper-Magnesium-Manganese) (B 89 – 42 T)	18	0	13
Spec. for Magnesium-Base Alloy Sheet (B 90 – 41 T)	17	0	14
Spec. for Magnesium-Base Alloy Forgings (B 91 – 41 T)	10	0	14
Spec. for Magnesium-Base Alloys in Ingot Form for Sand Castings and Die Castings (B 93 – 41 T)	15	0	7
Spec. for Magnesium-Base Alloy Bars, Rods, and Shapes (B 107 – 41 T)	12	0	12
Spec. for Aluminum-Base Alloy Permanent Mold Castings (B 108 – 43 T)	20	1	10
Spec. for Aluminum-Magnesium-Chromium Alloy Sheet and Plate (B 109 – 43 T)	17	0	14
Spec. for Aluminum-Manganese Alloy Sheet and Plate for Use in Welded Pressure Vessels (B 126 – 43 T)	18	0	13
Spec. for Aluminum Sheet and Plate for Use in Welded Pressure Vessels (B 178 – 43 T)	17	0	14
II. ADOPTION OF TENTATIVE STANDARD AS STANDARD			
Spec. for Aluminum Ingots for Remelting (B 24 – 41 T)	23	0	8

---

[a] To be used only where manganese is a primary constituent.

[b] To be used where the impurities iron and nickel are controlled to low limits.

Sealing of Anodically Coated Aluminum (B 136 – 40 T), and
Weight of Coating on Anodically Coated Aluminum (B 137 – 40 T).

In the case of Tentative Specifications B 37 and B 125, revisions are contemplated as soon as the necessary comments from consumers are available, and when data with respect to changes in the Standard Specifications for Aluminum-Base Alloy Die Castings (B 85 – 42) are received from Committee B-6 on Die-Cast Metals and Alloys.

The recommendations appearing in this report have been submitted to letter ballot of the committee, which consists of 55 members, with the results shown in Table I.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Aluminum and Aluminum Alloy Ingots (A. Sugar, chairman).—Following a review of the Tentative Specifications for Aluminum Ingots for Remelting (B 24 – 41 T), the subcommittee recommended that they be adopted as standard at this time. The subcommittee has also reviewed the other tentative specifications under its jurisdiction and will shortly recommend changes in the Tentative Specifications for Aluminum-Base Alloys in Ingot Form for Sand Castings (B 58 – 42 T) and for Permanent Mold Castings (B 112 – 41 T).[1] The contemplated changes are intended to bring these specifications in line with the respective product specifications. When recommendations have been received from Subcommittee I of Committee B-6 with respect to changes in the Standard Specifications for Aluminum-Base Alloy Die Castings (B 85 – 42), changes are contemplated in the Tentative Specifications for Aluminum-Base Alloys in Ingot Form for Die Castings (B 125 – 42 T).[1]

Subcommittee II on Aluminum Alloy Castings (R. W. Waring, chairman).—This subcommittee has prepared revisions in the Tentative Specifications for Aluminum-Base Alloy Sand Castings (B 26 – 43 T) and for Aluminum-Base Alloy Permanent Mold Castings (B 108 – 43 T), as given in the Appendix.

During the year at the request of Frankford Arsenal, the subcommittee collected data on the dimensional stability and resistance to corrosion of the various casting alloys. These data were developed on an unofficial basis, Mr. Waring acting as the clearing agent for such information as supplied by the various members. No definite future program of activities has been set up, but it is assumed that there will be further work required in connection with the specifications under its jurisdiction as the availability of the materials becomes more stable and consumer demands develop for other alloys.

Subcommittee III on Wrought Aluminum and Wrought Aluminum Alloys (P. V. Faragher, chairman).—A review has been made by this subcommittee of the various specifications under its jurisdiction in the light of present commercial practices. This has resulted in a number of changes in these specifications being recommended as detailed in the Appendix. It will be noted that these include the deletion of the product term "strip," this product now being commercially known as "coiled sheet."

Subcommittee IV on Magnesium and Magnesium Alloys, Cast and Wrought (H. W. Schmidt, chairman).—This subcommittee has prepared revisions in the five tentative specifications covering magnesium products under its jurisdiction. The detailed revisions are given in the Appendix. The subcommittee is at present developing an atmospheric exposure corrosion program of uncoated magnesium alloys and galvanic couples. This program is being formulated in cooperation with the Advisory Committee on Corrosion and Subcommittee VIII of Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys.

---

[1] See Editorial Note, p. 269.

Subcommittee V on Testing of Light Alloys (R. L. Templin, chairman).—This subcommittee has reviewed the cold bend testing procedure recommended for use with aluminum and magnesium, as covered by existing specifications. No changes appear necessary, the review indicating that no difficulties were being encountered in applying the present procedure.

Subcommittee VI on Anodic Oxidation of Aluminum and Aluminum Alloys (J. D. Edwards, chairman).—A review of the three tentative methods of testing anodic coatings (B 110, B 136, and B 137) has been made and the subcommittee recommends that they be continued as tentative without change. These methods were supplied to the British Standards Institute in answer to a request for information on means of appraising the quality of anodic coatings. The subcommittee has also offered to cooperate with them in developing any other methods that might be required.

The weather exposure tests on anodic coatings, reported in the 1943 annual report, are still being continued. Although no definite program for future work has been developed, there are several items that are contemplated for investigation as soon as materials and manpower are available. Several laboratories have offered their facilities for additional tests on aluminum and magnesium castings. The subcommittee plans to initiate work on a new program in the near future.

Subcommittee VII on Codification of Light Alloys (I. V. Williams, chairman).—A code system for the designation of magnesium-base alloys has been prepared by this subcommittee, the details of which are given earlier in this report.

The committee has voted to create a new subcommittee to plan and conduct corrosion tests, on products within the jurisdiction of the committee.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, D. L. Colwell.
Vice-Chairman, R. W. Waring.
Secretary, J. J. Bowman.

Respectfully submitted on behalf of the committee,

SAM TOUR,
Chairman.

H. J. ROWE,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting Committee B-7 presented to the Society through Committee E-10 on Standards the following recommendations:

Revision of Tentative Specifications for:

Aluminum-Base Alloys in Ingot Form for Sand Castings (B 58 – 42 T),
Aluminum-Base Alloys in Ingot Form for Permanent Mold Castings (B 112 – 41 T), and
Aluminum-Base Alloys in Ingot Form for Die Castings (B 125 – 42 T).

The first two recommendations were accepted by Committee E-10 on November 9, 1944, and the latter on November 13, 1944. The revised tentative specifications appear in the 1944 Book of A.S.T.M. Standards, Part I.

APPENDIX

RECOMMENDATIONS AFFECTING STANDARDS FOR LIGHT METALS AND ALLOYS, CAST AND WROUGHT

I. REVISIONS OF TENTATIVE STANDARDS

The committee recommends that the following sixteen tentative specifications be revised as indicated below and continued as tentative. These revisions are desired in the case of the specifications for wrought alloys to bring them in line with present commercial products as produced by the newer manufacturing methods. In the case of the specifications for casting alloys, the changes are desired to provide improved castings or greater availability of material.

Tentative Specifications for Aluminum Sheet and Plate (B 25 - 43 T):

The product formerly called "strip" now is termed "coiled sheet." Delete all references to "strip" in the text and substitute, where necessary, the term "coiled sheet."

Section 7 (b).—Reword the last paragraph to read as follows: "If so specified in the contract or order, plate shall be supplied in the soft temper, with a tensile strength of not less than 11,000 nor more than 15,000 psi., and an elongation in 2 in. of not less that 28 per cent."

Table I.—Change the minimum elongation for half-hard sheet in the thickness range of 0.114 to 0.249 in. from "7" to read "6" per cent.

Delete the present footnote and its references in the "elongation" column and substitute a new footnote "*a*" with appropriate references in the "temper" column to read as follows: "The maximum thickness of coiled sheet commercially available in the soft temper is 0.102 in., in the half-hard temper 0.085 in., and in the three-quarter hard temper 0.053 in."

Table II.—In the coiled sheet section of this table delete the entire first line and the entire last column since coiled sheet is no longer currently available in thicknesses over 0.102 in. or in widths greater than 24 in. Change the thickness tolerance for coiled sheet in the thickness range of 0.050 to 0.041 in., and width range of over 12 to 24 in. from "0.0025" to read "0.003" in.

Tentative Specifications for Aluminum-Base Alloy Sand Castings (B 26 - 43 T):

Section 1.—Delete the reference to alloys S3, and CS21 making the second sentence read as follows: "Eleven alloys are specified and are designated alloys C1, C2, G1, S1, S2, CG1, CN21, CS22, SC21, SG1, and ZG41. . . ."

Table I.—Change the requirements for chemical composition to those prescribed in the accompanying Table I, deleting alloys S3, and CS21.

Table II.—Change the requirements for tensile properties to those prescribed in the accompanying Table II, deleting alloys S3, and CS21.

Explanatory Note 1.—Delete the two Paragraphs referring to alloys S3, and CS21.

TABLE I.—CHEMICAL REQUIREMENTS.

NOTE 1.—Where single units are shown, these indicate the maximum amounts permitted.
NOTES 2 and 3.—These notes are to read the same as on the present table.

Alloy	Aluminum, per cent	Copper, per cent	Iron, per cent	Silicon, per cent	Magnesium, per cent	Manganese, per cent	Zinc, per cent	Nickel, per cent	Titanium, per cent	Other Elements, each, per cent	Other Elements, Total, per cent
C1....	Remainder	4.5 ± 0.5	1.0	1.5	0.03	0.3	0.3	....	0.2	0.05	0.15
C2.....	Remainder	$3.5\left\{\begin{matrix}+1.0\\-0.5\end{matrix}\right.$	1.2	2.5	0.05	0.5	0.5	0.3	0.2	....	0.3
G1 ...	Remainder	0.1	0.5	0.3	4.0 ± 0.5	0.6	0.1	....	0.2	0.05	0.15
S1.....	Remainder	0.1	0.8	$5.0\left\{\begin{matrix}+1.0\\-0.5\end{matrix}\right.$	0.05	0.3	0.3	....	0.2	0.05	....
S2......	Remainder	0.4	0.8	$5.0\left\{\begin{matrix}+1.0\\-0.5\end{matrix}\right.$	0.05	0.3	0.3	....	0.2	....	0.3
CG1....	Remainder	10.0 ± 0.8	1.5	1.0	0.25 ± 0.10	0.3	0.4	0.3	0.2	....	0.3
CN21...	Remainder	4.0 ± 0.5	1.0	0.7	1.5 ± 0.3	0.3	0.1	2.0 ± 0.3	0.2	0.05	0.15[a]
CS22....	Remainder	7.0 ± 1.0	1.4	2.0 ± 1.0	0.07	0.5	2.5	0.3	0.2	....	0.5
SC21....	Remainder	1.25 ± 0.25	0.6	5.0 ± 0.5	0.5 ± 0.1	0.1	0.3	....	0.2	0.05	0.15[a]
SG1.....	Remainder	0.2	0.6	7.0 ± 0.5	0.3 ± 0.1	0.3	0.3	....	0.2	0.05	0.15
ZG41...	Remainder	0.2	1.0	0.25	0.6 ± 0.1	....	5.5 ± 0.5	....	0.2 ± 0.1	0.05	[b]

[a] Chromium 0.2 per cent.
[b] Chromium 0.5 ± 0.1 per cent.

Insert before the last sentence in the Paragraph on *Alloy C1* the following sentence: "Heat treatment No. 4 is a solution treatment followed by an 'over aging' precipitation treatment to relieve residual stresses and minimize permanent dimensional changes in castings that are subject to heating in service."

Change the Paragraph on alloy CS22 to read as follows: "The specific gravity of alloy CS22 is about 2.83 to 2.86. The pattern shrinkage is about 0.156 $(\frac{5}{32})$ in. per ft. It supersedes the 8 per cent copper alloy without silicon, as it possesses better casting characteristics, especially in the more difficult work. It has excellent machining qualities. This alloy is used for general casting purposes.

Change the Paragraph on alloy SC21, after the third sentence to read as follows: "Heat treatment No. 1, consisting of a solution and precipitation treatment, provides optimum combination of strength and ductility for this alloy. Heat treatment No. 2 is a precipitation treatment only and serves to stabilize dimensions in parts subject to heating in service. Heat treatment No. 3 is a solution treatment followed by an 'over aging' precipitation treatment to relieve residual stresses and minimize permanent dimensional changes in castings subject to heating in service."

TABLE II.—TENSILE REQUIREMENTS.

Alloy	Condition	Tensile Strength min., psi.	Elongation in 2 in., min., per cent
C1....	Heat treatment No. 1....	29 000	6
	Heat treatment No. 2....	32 000	3
	Heat treatment No. 3....	36 000	[a]
	Heat treatment No. 4....	29 000	3
C2.......	Heat treatment No. 1....	27 000	3
G1.......	As-cast..................	22 000	6
S1.......	As-cast..................	17 000	3
S2.......	As-cast..................	17 000	3
CG1...	Heat treatment No. 1....	23 000	[a]
	Heat treatment No. 2....	30 000	[a]
CN21..	Heat treatment No. 1....	23 000	[a]
	Heat treatment No. 2....	32 000	[a]
CS22....	As-cast..................	19 000	1[b]
SC21..	Heat treatment No. 1....	32 000	2
	Heat treatment No. 2....	25 000	[a]
	Heat treatment No. 3....	30 000	[a]
SG1...	Heat treatment No. 1....	30 000	3
	Heat treatment No. 2....	23 000	[a]
ZG41...	Aged.....................	30 000	3

[a] Not required.
[b] For information only.

Change the Paragraph on alloy SG1 to read as follows: "The specific gravity of alloy SG1 is about 2.65. It has casting qualities and resistance to corrosion comparable with those of alloy S1 (see Note on alloy S1). Its higher mechanical properties result from heat treatment processes. Heat treatment No. 1 is a solution and precipitation heat treatment providing the optimum combination of tensile strength and elongation. Heat treatment No. 2 is a precipitation treatment only and serves to stabilize dimensions in parts subject to heating in service.

TABLE III.—TYPICAL YIELD STRENGTHS.

Alloy	Condition	Typical Yield Strength (0.2 per cent offset), psi.
C1	Heat treatment No. 1	16 000
	Heat treatment No. 2	22 000
	Heat treatment No. 3	31 000
	Heat treatment No. 4	19 000
C2	Heat treatment No. 1	16 000
G1	As-cast	12 000
S1	As-cast	9 000
S2	As-cast	9 000
CG1	Heat treatment No. 1	20 000
	Heat treatment No. 2	30 000
CN21	Heat treatment No. 1	20 000
	Heat treatment No. 2	32 000
CS22	As-cast	14 000
SC21	Heat treatment No. 1	25 000
	Heat treatment No. 2	23 000
	Heat treatment No. 3	29 000
SG1	Heat treatment No. 1	22 000
	Heat treatment No. 2	20 000
ZG41	Aged	25 000

Explanatory Note 2.—Revise, where required, the present table in this Paragraph showing typical yield strengths to conform to the requirements prescribed in the accompanying Table III.

Appendix.—Delete the data for alloys S3, and CS21 from the table of supplementary data.

Tentative Specifications for Aluminum-Alloy (Duralumin) Sheet and Plate Aluminum-Copper-Magnesium-Manganese (B 78 – 42 T):

Table I.—In the "Heat Treated" section of this table revise the minimum tensile strength of material of all thicknesses up to 1.500 in. from "55,000" to read "58,000" psi., and of material of thicknesses from 1.501 to 2.000 in. from "52,000" to read "55,000" psi., and for material 2.001 to 3.000 in. from "50,000" to read "55,000" psi. Change the minimum yield strength values for all thicknesses of heat-treated material from "32,000" to read "34,000" psi. Add a footnote to the effect that material heat treated by the user shall show a minimum yield strength of 33,000 psi.

Table II.—Change the heading of the upper section of the table from "Sheet" to read "Flat Sheet" and the heading of the lower section of the table from "Strip" to read "Coiled Sheet."

Section 15.—Add the following sentence to this section: "In case of rejection, the responsibility of the manufacturer shall be limited to replacing the material with other material which conforms to the requirements of these specifications, without charge to the purchaser."

Tentative Specifications for Aluminum-Manganese Alloy Sheet and Plate (B 79 – 43 T):

Delete all reference to "strip" substituting the words "coiled sheet," where necessary.

Section 7(b).—Reword the last paragraph to read as follows: "If so specified in the contract or order, plate shall be supplied in the soft temper, with a tensile strength of not less than 14,000 nor more than 21,000 psi., and an elongation in 2 in. of not less than 18 per cent."

Table I.—Change the first thickness

range for half-hard sheet, namely, "0.010 to 0.019" to read "0.013 to 0.019" in., and reduce the elongation requirements for half-hard sheet in the thickness ranges of 0.114 to 0.161 and 0.162 to 0.249 from "7" and "8," respectively, to read "6" and "7" per cent, respectively.

Table I.—Make the same changes to the footnote in this table as recommended above for Table I in Specifications B 25.

Table II.—In the section of the table on "Coiled Sheet" delete the entire first line and the entire column and change the thickness tolerance for coiled sheet in the thickness range of 0.050 to 0.041 in. and width range of over 12 to 24 in. from "0.0025" to read "0.003" in.

Tentative Specifications for Magnesium-Base Alloy Sand Castings (B 80 – 41 T):

Alloy Designations.—In accordance with the code designations discussed earlier in the report, change the alloy designations to read as follows:

Proposed Designation	Present Designation
A10	2
A12	3
AZ63	4
AZ63X	4X
M1	11
AZ101	14
AZ92	17
AZ92X	17X

Tentative Specifications for Aluminum Alloy (Duralumin) Bars, Rods, Wire, and Shapes (B 89 – 42 T):

Table I.—Replace this table with the accompanying Table IV.

Section 14.—Add the following sentence at the end of this section: "In case of rejection, the responsibility of the manufacturer shall be limited to replacing the material with other material which conforms to the requirements of these specifications, without charge to the purchaser."

Tentative Specifications for Magnesium-Base Alloy Sheet (B 90 – 41 T):

Alloy Designations.—In accordance with the code designations discussed earlier in the report, change the alloy designations to read as follows:

Proposed Designation	Present Designation
A6	7
AZ61	8
AZ61X	8X
M1	11
AZ31	18
AZ31X	18X

Section 1.—Change the second sentence to read as follows: "Three types of alloys are specified and are designated alloys Nos. 8, 11, and 18 (see Explanatory Note 1)."

Table I.—Delete the chemical requirements for alloy No. 7 and change the requirements for aluminum in alloys Nos. 18 and 18X from "2.4 to 3.0" to read "2.5 to 3.5" per cent.

Table II.—Replace this table with the accompanying Table V.

Explanatory Note 1.—Delete the first Paragraph referring to alloy No. 7.

In the Paragraph referring to alloy No. 8 delete the second sentence and replace it with the following: "It is characterized by good physical properties."

In the Paragraph referring to alloy No. 11 delete the second sentence and replace it with the following: "Its resistance to salt water corrosion is superior to alloys 8 and 18, but inferior to alloys 8X and 18X."

Explanatory Note 2.—In Table III delete all reference to alloy No. 7.

Tentative Specifications for Magnesium-Base Alloy Forgings (B 91 – 41 T):

Alloy Designations.—In accordance with the code designations discussed

TABLE IV.—TENSILE REQUIREMENTS.

Section	Diameter or Least Distance Across Flats	Tensile Strength, psi.	Yield Strength, min., psi.[a]	Elongation, min., per cent[b]
		ANNEALED		
Rounds, Squares, Hexagons, Octagons, and Rectangles	Up to 0.125 in. 0.125 in. and over	35 000 max. 35 000 max.	....	 16
Rolled or Extruded Shapes	all sizes	35 000 max.	....	12
		HEAT TREATED		
Rounds, Squares, Hexagons, Octagons, and Rectangles	Up to 0.125 in. 0.125 to 0.374 in. 0.375 and over	55 000 min. 55 000 min. 55 000 min.	.... 32 000 32 000	.... 14 12
Rolled or Extruded Shapes	all sizes	50 000 min.	32 000	12

[a] Yield strength is defined as the stress which produces a permanent set of 0.2 per cent of the initial gage length.

[b] The gage length for measurement of elongation shall be equal to four times the diameter or distance across flats except in sections for which a flat tension test specimen is used in which case the gage length shall be 2 in.

TABLE V.—TENSILE REQUIREMENTS.

Alloy	Condition	Tensile Strength, min., psi.	Yield Strength, (0.2 per cent offset), min., psi.	Elongation in 2 in., min., per cent
Nos. 8 and 8X	Hard rolled (H) Annealed (A)	42 000 37 000	29 000	2 5
No. 11	Hard rolled (H) Annealed (A)	32 000 28 000	21 000	3 7
Nos. 18 and 18X	Hard rolled (H) Annealed (A)	38 000 32 000	24 000	4 11

earlier in the report, change the alloy designations to read as follows:

Proposed Designation	Present Designation
AZ61	8
AZ61X	8X
AZ80	9
AZ80X	9X
AZ33	15
AZ33X	15X
AT35	16
AZ31	18
AZ31X	18X

Table I.—Change the chemical limits for manganese in alloys Nos. 9 and 9X from "0.15" to read "0.12" min., per cent.

Tentative Specifications for Magnesium-Base Alloys in Ingot Form for Sand Castings and Die Castings (B 93 – 41 T):

Alloy Designations.—In accordance with the code designations discussed earlier in the report, change the alloy designations to read as follows:

Proposed Designation	Present Designation
A10	2
A12	3
AZ63	4
AZ63X	4X
M1	11
AS100	12
AZ90	13
AZ90X	13X
AZ101	14
AZ92	17
AZ92X	17X

Table I.—In alloy 13X change the limit of nickel from "0.003" to read "0.002" max., per cent.

Delete Note 1 and renumber Note 2 as Note 1.

Tentative Specifications for Magnesium-Base Alloy Bars, Rods, and Shapes (B 107 – 41 T):

Alloy Designations.—In accordance with the code designations discussed earlier in the report, change the alloy designations to read as follows:

Proposed Designation	Present Designation
AZ61	8
AZ61X	8X
AZ80	9
AZ80X	9X
M1	11
AZ33	15
AZ33X	15X
AZ31	18
AZ31X	18X

Table I.—In alloys Nos. 18 and 18X change the requirements for aluminum from "2.4 to 3.0" to read "2.5 to 3.5" per cent.

In alloys Nos. 9 and 9X change the limit of manganese from "0.15" to read "0.12" min., per cent.

Table II.—Revise the tensile requirements for alloys 8, 8X, 9, 9X, 11, 18, and 18X to read as shown in the accompanying Table VI.

TABLE VI.—TENSILE REQUIREMENTS.

Alloy	Shape and Size	Tensile Strength, min., psi.	Yield Strength (0.2 per cent offset), min., psi.	Elongation in 2 in., min., per cent
Nos. 8 and 8X	Round and Square up to 1½ in.	40 000	26 000	11
	Structural Shapes	40 000	22 000	9
Nos. 9 and 9X	Round and Square up to 1½ in.	43 000	28 000	9
	Structural Shapes	41 000	25 000	6
No. 11	Round and Square up to 1½ in.	30 000	....	3
	Structural Shapes	29 000	....	3
Nos. 18 and 18X	Round and Square up to 1½ in.	35 000	22 000	10
	Structural Shapes	33 000	20 000	8

Tentative Specifications for Aluminum-Base Alloy Permanent Mold Castings (B 108 – 43 T):

Section 1.—Revise the second sentence to read as follows: "Ten alloys are specified and are designated alloys C3, S1, S2, CG1, CN21, CS4, SC1, SC41, SG1, and SN41."

Section 2.—Delete the entire section and renumber subsequent sections accordingly.

Table I.—Change the requirements for chemical composition to those prescribed in the accompanying Table VII.

TABLE VII.—CHEMICAL REQUIREMENTS.

Note 1.—Where single units are shown, these indicate the maximum amounts permitted.
Notes 2 and 3.—These notes are to read the same as on the present table.

Alloy	Aluminum, per cent	Copper, per cent	Iron, per cent	Silicon, per cent	Magnesium, per cent	Manganese, per cent	Zinc, per cent	Nickel, per cent	Other Elements, Each, per cent	Other Elements, Total per cent
C3	Remainder	7.0 ± 1.0	1.4	4.0	0.07	0.5	2.5	0.3	....	0.5
S1	Remainder	0.1	0.8	$5.0\begin{cases}+1.0\\-0.5\end{cases}$	0.05	0.3	0.3	....	0.05	....
S2	Remainder	0.4	0.8	$5.0\begin{cases}+1.0\\-0.5\end{cases}$	0.05	0.3	0.3	....	....	0.3
CG1	Remainder	10.0 ± 0.8	1.5	1.0	0.25 ± 0.10	0.3	0.4	0.3	....	0.3
CN21	Remainder	4.0 ± 0.5	1.0	0.7	1.5 ± 0.3	0.3	0.1	2.0 ± 0.3	0.05	0.15[a]
CS4	Remainder	4.5 ± 0.5	1.2	2.5 ± 0.5	0.05	0.3	0.3	0.3	....	0.3
SC1	Remainder	4.5 ± 0.5	1.0	5.5 ± 0.5	0.1	0.3	0.5	....	....	0.5
SC41	Remainder	1.5 ± 0.5	0.9	12.25 ± 0.75	0.55 ± 0.15	0.75 ± 0.15	0.4	0.05	....	0.5
SG1	Remainder	0.2	0.6	7.0 ± 0.5	0.3 ± 0.1	0.3	0.3	....	0.05	0.15
SN41	Remainder	1.0 ± 0.5	1.3	12.0 ± 1.0	1.0 ± 0.3	0.1	0.1	2.5 ± 0.5	0.05	....

[a] Chromium 0.2 per cent.

NOTE.—Titanium is permissible in all alloys, but the maximum shall not exceed 0.2 per cent.

Table II.—Change the requirements for tensile properties to those prescribed in the accompanying Table VIII.

Appendix.—Delete the data referring to alloys Nos. S6 and CS23.

TABLE VIII.—TENSILE REQUIREMENTS.

Alloy	Condition	Tensile Strength min., psi.	Elongation in 2 in., min., per cent
C3......	As-cast..................	23 000	[a]
S1.......	As-cast..................	21 000	2.5
S2.......	As-cast..................	21 000	2
CG1...	Heat treatment No. 1.... Heat treatment No. 2....	30 000 40 000	[a] [a]
CN21..	Heat treatment No. 1.... Heat treatment No. 2....	34 000 40 000	[a] [a]
CS4...	Heat treatment No. 1.... Heat treatment No. 2.... Heat treatment No. 3....	33 000 35 000 33 000	4.5 2.0 3.0
SC1......	As-cast..................	23 000	[a]
SC41...	Heat treatment No. 1.... Heat treatment No. 2....	32 000 36 000	[a] [a]
SG1......	Heat treatment No. 1....	33 000	3.0
SN41..	Heat treatment No. 1.... Heat treatment No. 2....	31 000 40 000	[a] [a]

[a] Not required.

Tentative Specifications for Aluminum-Magnesium-Chromium Alloy Sheet and Plate (B 109 – 43 T):

Table 1.—Delete the present footnote "*a*" and its reference. Supply a new footnote "*a*" in the "temper" column after all tempers except the "hard" temper to read as follows: "The maximum thickness of coiled sheet commercially available in the soft and one-quarter-hard tempers is 0.102 in., in the half-hard temper 0.085 in., and in the three-quarter-hard temper 0.053 in.

Section 7 (b).—In the table change the minimum required elongation of half-hard plate from "8" to read "7" per cent.

Table II.—Delete the entire first line and the entire last column from the coiled sheet section and change the thickness tolerance for coiled sheet in the thickness range of 0.050 to 0.041 in. and the width range of over 12 to 24 in. from "0.0025" to read "0.003" in.

Section 15.—Add the following sentence at the end of the section: "In case of rejection, the responsibility of the manufacturer shall be limited to replacing the material with other material which conforms to the requirements of these specifications, without charge to the purchaser."

Tentative Specifications for Aluminum-Manganese Alloy Sheet and Plate for Use in Welded Pressure Vessels (B 126 – 43 T):

Delete all references to "strip" and substitute the words "coiled sheet," where necessary.

Table I.—Delete the present footnote "*a*" and its reference in the elongation column. Add a few footnote reference "*a*" after first two tempers in "temper" column, the new footnote to read as follows: "Coiled sheet is commercially available in thicknesses up to 0.102 in."

Change the designation "annealed" to read "soft."

Section 8.—Change the word "annealed" to read "soft" in the second line of Paragraph (*a*) and revise the second sentence of Paragraph (*b*) to read, in part: "The bend test specimen . . . or from as-rolled plate shall. . . ."

Table II.—Delete from the "flat sheet" section, the column for "18 in. and under" and change the heading on the next column to read "36 in. and under in width."

Delete the entire first line and the entire last column from the coiled sheet section and change the thickness tolerance for the thickness range of 0.050 to 0.041 in. and the width range of over 12 to 24 in. from "0.0025" to read "0.003" in.

Tentative Specifications for Aluminum Sheet and Plate for Use in Welded Pressure Vessels (B 178 – 43 T):

Delete all references to "strip" and substitute the words "coiled sheet," where necessary.

Table I.—Revise the tension requirements by deleting the values given in the first line for the "soft" temper and substituting the following:

Thickness, in.	Tensile Strength, min., psi.	Elongation in 2 in., min., per cent
0.010 to 0.019....	11 000	15
0.020 to 0.031....	11 000	20

Change the elongation values required for the thickness range of 0.250 to 2.000 in. from "25" to read "28" per cent.

Change the elongation values required for quarter-hard material for the thickness range of 0.051 to 0.113 in. from "7" to read "8" per cent. For the as-rolled temper, add a thickness range of "0.626 to 2.000 in." with a tensile strength of "12,000 psi." and an elongation of "9 per cent."

Section 8.—Delete Paragraph (*b*) from this section.

Table II.—Delete the entire first line and the entire last column from the "coiled sheet" section and change the thickness tolerance for the thickness range of 0.050 to 0.041 in. and width range of over 12 to 24 in. from "0.0025" to read "0.003" in.

REPORT OF COMMITTEE B-8
ON
ELECTRODEPOSITED METALLIC COATINGS

Committee B-8 on Electrodeposited Metallic Coatings held two meetings during the past year: in Pittsburgh, Pa., on June 29, 1943, and in Cincinnati, Ohio, on March 1, 1944.

The membership of the committee now totals 74, of whom 30 are classified as producers, 8 as consumers, and 36 as general interest members.

TENTATIVE STANDARDS CONTINUED AS TENTATIVE

The committee recommends that the following tentative specifications and methods of test be continued as tentative for another year pending their contemplated revision:

Tentative Specifications for:

Electrodeposited Coatings of Nickel and Chromium on Steel (A 166 - 41 T),
Electrodeposited Coatings of Nickel and Chromium on Copper and Copper-Base Alloys (B 141 - 41 T),
Electrodeposited Coatings of Nickel and Chromium on Zinc and Zinc-Base Alloys (B 142 - 41 T), and

Tentative Methods of Test for:

Local Thickness of Electrodeposited Coatings (A 219 - 40 T).

The committee also recommends that the following tentative recommended practices be continued as tentative without revision:

Tentative Recommended Practices for:

Chromium Plating on Steel for Engineering Use (B 177 - 43 T), and
Preparation of Low-Carbon Steel for Electroplating (B 183 - 43 T).

It is recommended that the Emergency Specifications for Electrodeposited Coatings of Lead on Steel (ES - 31) be continued without change.

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 66 voting members; 59 members returned their ballots of whom 55 have voted affirmatively, 0 negatively, and 4 members marked their ballots "not voting."

ACTIVITIES OF SUBCOMMITTEES

Subcommittee II on Performance Tests (H. A. Pray, chairman) has initiated a series of atmospheric exposure tests of electroplated lead coatings on steel. The specimens have been prepared and exposed at four locations as described in the detailed report of this subcommittee which is appended hereto.

Subcommittee III on Conformance Tests (C. H. Sample, chairman) has initiated through a subgroup, of which W. A. Wesley is chairman, experimental work relative to the mechanism of corrosion through pores.

Subcommittee IV on Electroplating Practice (A. K. Graham, chairman) has begun an informal survey of the current practice of preparing high-carbon steel for electroplating looking toward the preparation of a recommended practice on that subject.

Subcommittee V on Supplementary Protective Finishes for Metallic Coatings

(L. G. Tubbs, chairman) reluctantly accepted the resignation of its original chairman, B. H. McGar. The subcommittee has not been active during the year.

The present officers of the committee have been re-elected for the ensuing term of two years.

This report has been submitted to letter ballot of the committee which consists of 66 voting members; 59 members returned their ballots, of whom 54 have voted affirmatively, and 2 negatively.

Respectfully submitted on behalf of the committee,

R. J. McKAY
Chairman.

C. H. SAMPLE,
Secretary.

REPORT OF SUBCOMMITTEE II ON PERFORMANCE TESTS

During the past year Subcommittee II has been engaged in the initiation of atmospheric exposure tests of electroplated lead coatings on steel. The purpose of the tests is to determine the effect of lead thickness, the type of plating bath, the presence or absence of a thin copper undercoating, and of physical damage to the coating on the useful life of such coatings in various atmospheres.

Plan of the Tests

Four exposure stations were selected as offering relatively pure typical atmospheres. Facilities were available at New York, N. Y. (industrial), State College, Pa. (rural), and Kure Beach, Wilmington, N. C. (seacoast). Facilities were also made available[1] at Tela, Honduras (tropical).

The tests involve 148 panels at each of the four exposure stations and include various thicknesses of lead from the two commercial plating baths applied to steel, copper-plated steel, and copper; electroplated lead-tin alloy coatings of two compositions on steel; hot-dipped lead alloys of two compositions; electroplated and hot-dipped zinc; intentionally damaged electroplated lead on steel; and the necessary bare steel controls. The general plan is set forth in Table I. The schedule provides triplicate panels for visual inspection; two additional panels, in certain cases, for a determination of loss in tensile strength; and twelve additional panels, in two cases, for periodic weight loss measurements to determine the rate of weathering of the electroplated lead itself in the different atmospheres.

Preparation of the Panels[2]

The 4 by 6-in. steel panels for plating were obtained from a commercial warehouse. They were received with a No. 3 finish, No. 4 temper, and No. 3 edge. Their chemical analysis was as follows: carbon 0.06, silicon 0.005, manganese 0.34, copper 0.11, phosphorus 0.005, and sulfur 0.032 per cent. The 4 by 6-in. copper panels were cut from commercial hard 24-oz. (0.031 in.) sheet produced to meet requirements of 50,000 psi., 5 per cent elongation, Rockwell F 90 specification.

All plated panels were processed on identical racks, each holding twelve panels, and with identical tank equipment, anode arrangement, and current source to insure comparative, if not strictly commercially representative, samples.

The processing procedure comprised:

1. Vapor degreasing (stabilized trichlorethylene),
2. Cathodic cleaning, 1 min., 50 amp. per sq. ft., 195 F. or higher, in 5.5 oz. per gal. sodium hydroxide, 5.0 oz. per gal. sodium metasilicate, and 0.03 oz. per gal. Duponol ME dry,
3. Hot water rinsing,
4. Dipping in 3*N* hydrochloric acid, 20 to 40 sec. at room temperature,
5. Cold water rinsing,
6. Cyanide copper plating,
7. Cold water rinsing,
8. Lead plating,
9. Cold water rinsing,

---

[1] By arrangement with the United Fruit Co.

[2] The work involved in the preparation of the specimens was done at Battelle Memorial Institute as part of an investigation of lead coatings conducted for the War Metallurgy Committee of the National Research Council at the request of the Conservation Division, War Production Board.

10. Warm water rinsing, and
11. Drying;

or:

6. Lead plating,
7. Cold water rinsing,
8. Warm water rinsing, and
9. Drying.

TABLE I.—OUTLINE OF EXPOSURE TESTS.

Type Coating	Nominal Coating Thickness, in.	Number of Panels (Each Station) for			
		Visual Examination	Tension Test	Weight Loss	Effect of Damage
Sulfamate lead on steel	0.00050	3	2	...	...
	0.00100	3	2	...	...
Fluoborate lead on steel	0.00008	3	...	...	...
	0.00025	3	2	...	...
	0.00050	3	2	...	3
	0.00075	3	2	...	...
	0.00100	3	2	...	...
	0.00200	3	2	12	3
Sulfamate lead on copper-plated[a] steel	0.00050	3	2	...	...
	0.00100	3	2	...	...
Fluoborate lead on copper-plated[a] steel	0.00008	3	...	...	...
	0.00025	3	2	...	...
	0.00050	3	2	...	3
	0.00075	3	2	...	...
	0.00100	3	2	...	3
	0.00200	3	2	12	...
Sulfamate lead on sheet copper	0.00025	3	...	...	...
	0.00050	3	...	...	...
Fluoborate lead on sheet copper	0.00025	3	...	...	...
	0.00050	3	...	...	...
Sulfomate lead-tin (2 per cent tin) on steel	0.00100	3	...	...	...
Sulfamate lead-tin (10 per cent tin) on steel	0.00100	3	...	...	...
Commercial hot-dipped terne (20 per cent tin)	0.00017	3	...	...	...
Commercial hot-dipped lead (2.5 per cent tin, 2 per cent antimony)	0.00040	3	...	...	...
Electroplated zinc on steel	0.00020	3	...	...	...
Hot-dipped zinc on steel	0.00075	3	...	...	...
Bare steel	...	...	6	...	...

[a] Copper plate 0.000015 in.

The cyanide copper bath contained:

10 oz. per gal. sodium cyanide,
7 oz. per gal. cuprous cyanide,
3 oz. per gal. sodium carbonate, and
0.016 oz. per gal. sodium thiosulfate,

and was operated at 20 amp. per sq.ft. cathode and 14 amp. per sq. ft. anode current density, without agitation, at 100 to 115 F.

The fluoborate lead bath was prepared from commercial concentrate. It contained:

25 oz. per gal. of lead (35° Baumé solution), and
0.054 oz. per gal. bone glue,

and was operated at 20 amp. per sq. ft. cathode, 15 amp. per sq. ft. anode current density, without agitation, at 80 F. and pH below 1.5.

The sulfamate lead bath was made up using commercially prepared salts. It contained 50 oz. per gal. of the prepared plating salts and 1.3 oz. per gal. of a proprietary addition agent designated as No. 1. The bath was operated at 20 amp. per sq. ft. anode and cathode current density, without agitation, at 80 F. and pH 1.4 to 2.4.

The sulfamate bath used for plating the lead-tin alloys contained 48 oz. per gal. of the prepared sulfamate plating salts and 1 oz. per gal. of the proprietary addition agent No. 3. Metallic tin was introduced into this bath anodically until the concentration of tin in the bath was sufficient to produce an alloy deposit of the required composition.

The electroplated zinc was deposited from a bath containing:

7 oz. per gal. zinc cyanide,
4 oz. per gal. sodium cyanide, and
7 oz. per gal. sodium hydroxide,

and was operated at 25 amp. per sq. ft. cathode current density, without agitation, and at 100 F.

The hot-dipped panels were obtained from commercial sources in the form of large sheets, and they were cut from these sheets far enough from the edge to insure uniform coating thickness. A 1 by 2-in. specimen, for thickness determination and analysis, was cut from the sheet adjacent to each of the four edges of each of the exposure panels. The cut edges of the galvanized specimens were zinc plated and those of the lead alloy panels

TABLE II.—PANEL IDENTIFICATION.

Base	Plating Bath	Nominal Lead Coating Thickness, in.	Purpose	Specimen Number	Designation
Bare steel	Sulfamate	0.0005 Pb	Visual examination	1-12	S-5-S-(1-12)
		0.0005 Pb.	Tensile test	13-24	S-5-S-(13-24)
		0.001 Pb	Visual examination	25-36	S-10-S-(1-12)
		0.001 Pb	Tensile test	37-48	S-10-S-(13-24)
	Fluoborate	0.00025 Pb	Visual examination	49-60	S-2-F-(1-12)
		0.00025 Pb	Tensile test	61-72	S-2-F-(13-24)
		0.0005 Pb	Visual examination	73-84	S-5-F-(1-12)
		0.0005 Pb	Tensile test	85-96	S-5-F-(13-24)
		0.0005 Pb	Damage	97-108	S-5-F-(25-36)
		0.00075 Pb	Visual examination	109-120	S-7-F-(1-12)
		0.00075 Pb	Tensile test	121-132	S-7-F-(13-24)
		0.001 Pb	Visual examination	133-144	S-10-F-(1-12)
		0.001 Pb	Tensile test	145-156	S-10-F-(13-24)
		0.001 Pb	Damage	157-168	S-10-F-(25-36)
		0.002 Pb	Visual examination	169-180	S-20-F-(1-12)
		0.002 Pb	Tensile test	181-192	S-20-F-(13-24)
		0.002 Pb	Weight loss	193-204	S-20-F-(25-36)
		0.002 Pb	Weight loss	205-216	S-20-F-(37-48)
		0.002 Pb	Weight loss	217-228	S-20-F-(49-60)
		0.002 Pb	Weight loss	229-240	S-20-F-(61-72)
Copper-plated[a] steel	Sulfamate	0.0005 Pb	Visual examination	241-252	C-5-S-(1-12)
		0.0005 Pb	Tensile test	253-264	C-5-S-(13-24)
		0.001 Pb	Visual examination	265-276	C-10-S-(1-12)
		0.001 Pb	Tensile test	277-288	C-10-S-(13-24)
	Fluoborate	0.00025 Pb	Visual examination	289-300	C-2-F-(1-12)
		0.00025 Pb	Tensile test	301-312	C-2-F-(13-24)
		0.0005 Pb	Visual examination	313-324	C-5-F-(1-12)
		0.0005 Pb	Tensile test	325-336	C-5-F-(13-24)
		0.0005 Pb	Damage	337-348	C-5-F-(25-36)
		0.00075 Pb	Visual examination	349-360	C-7-F-(1-12)
		0.00075 Pb	Tensile test	361-372	C-7-F-(13-24)
		0.001 Pb	Visual examination	373-384	C-10-F-(1-12)
		0.001 Pb	Tensile test	385-396	C-10-F-(13-24)
		0.001 Pb	Damage	397-408	C-10-F-(25-36)
		0.002 Pb	Visual examination	409-420	C-20-F-(1-12)
		0.002 Pb	Tensile test	421-432	C-20-F-(13-24)
		0.002 Pb	Weight loss	433-444	C-20-F-(25-36)
		0.002 Pb	Weight loss	445-456	C-20-F-(37-48)
		0.002 Pb	Weight loss	457-468	C-20-F-(49-60)
		0.002 Pb	Weight loss	469-480	C-20-F-(61-72)
Sheet copper	Sulfamate	0.00025 Pb	Visual examination	481-492	B-2-S-(1-12)
		0.0005 Pb	Visual examination	493-504	B-5-S-(1-12)
	Fluoborate	0.00025 Pb	Visual examination	505-516	B-2-F-(1-12)
		0.0005 Pb	Visual examination	517-528	B-5-F-(1-12)
Bare steel	Hot dipped	20 per cent Sn	Visual examination	529-540	T-(1-12)
		2.5 per cent Sn, 2 per cent Sb	Visual examination	541-552	A-(1-12)
	Zinc plated	0.0002 Zn	Visual examination	577-588	G-2-(1-12)
	Hot dipped	0.001 Zn	Visual examination	589-600	G-10-(1-12)
	No coating	.....	Tensile test	601-624	O-(1-24)
	Lead-tin sulfamate 2 per cent	0.001	Visual examination	625-648	S-10-A2-(1-24)
	Lead-tin sulfamate 10 per cent	0.001	Visual examination	649-672	S-10-A10-(1-24)
	Fluoborate	0.00025 Pb	Storage	673-684	S-2-F-(1-12)
		0.00050 Pb	Storage	685-696	S-5-F-(1-12)
		0.00075 Pb	Storage	697-708	S-7-F-(1-12)
		0.00100 Pb	Storage	709-720	S-10-F-(1-12)
		0.00200 Pb	Storage	721-732	S-20-F-(1-12)
	Sulfamate	0.00050 Pb	Storage	733-744	S-5-S-(1-12)
		0.00100 Pb	Storage	745-756	S-10-S-(1-12)
	Fluoborate	0.000085 Pb	Visual examination	757-768	S-08-F-(1-12)
		0.000085 Pb	Visual examination	769-780	S-08-F-(13-24)
Copper-plated[a] steel	Fluoborate	0.000085 Pb	Visual examination	781-792	C-08-F-(1-12)
		0.000085 Pb	Visual examination	793-804	C-08-F-(13-24)

[a] Copper plate 0.000015 in. thick.

TABLE III.—DESCRIPTION OF EXPOSURE PANELS.

Designation Symbol	Panel Number	Position on Plating Rack	Total Weight, g.	Weight of Deposit, g.	Calculated Average Deposit Thickness, in.	Variation from Nominal Thickness, per cent	Average Thickness of Steel, in.	Designation Symbol	Panel Number	Position on Plating Rack	Total Weight, g.	Weight of Deposit, g.	Calculated Average Deposit Thickness, in.	Variation from Nominal Thickness, per cent	Average Thickness of Steel, in.
S-5-S-1	1	1	115.67	4.71	0.00053	+6	....	S-5-F-1	73	1	115.58	4.84	0.00054	+8	....
S-5-S-2	2	2	116.04	4.69	0.00052	+4	....	S-5-F-2	74	2	113.55	4.80	0.00054	+8	....
S-5-S-3	3	3	115.69	4.68	0.00052	+4	....	S-5-F-3	75	3	113.78	4.76	0.00053	+6	....
S-5-S-4	4	4	115.45	4.81	0.00054	+8	....	S-5-F-4	76	4	113.96	4.72	0.00053	+6	....
S-5-S-5	5	5	113.66	4.79	0.00054	+8	....	S-5-F-5	77	5	115.70	4.73	0.00053	+6	....
S-5-S-6	6	6	112.93	4.77	0.00053	+6	....	S-5-F-6	78	6	116.87	4.81	0.00054	+8	....
S-5-S-7	7	7	116.44	4.80	0.00054	+8	....	S-5-F-7	79	7	114.34	4.74	0.00053	+6	....
S-5-S-8	8	8	115.53	4.81	0.00054	+8	....	S-5-F-8	80	8	113.77	4.74	0.00053	+6	....
S-5-S-9	9	9	115.55	4.79	0.00054	+8	....	S-5-F-9	81	9	112.20	4.77	0.00053	+6	....
S-5-S-10	10	10	115.64	4.76	0.00053	+6	....	S-5-F-10	82	10	115.36	4.66	0.00052	+4	....
S-5-S-11	11	11	114.15	4.81	0.00054	+8	....	S-5-F-11	83	11	116.73	4.76	0.00053	+6	....
S-5-S-12	12	12	115.04	4.83	0.00054	+8	....	S-5-F-12	84	12	116.49	4.77	0.00053	+6	....
S-5-S-13	13	1	113.54	4.22	0.00047	−6	0.035	S-5-F-13	85	1	112.40	4.34	0.00049	−2	0.035
S-5-S-14	14	2	113.39	4.20	0.00047	−6	0.035	S-5-F-14	86	2	113.02	4.27	0.00048	−4	0.035
S-5-S-15	15	3	115.32	4.18	0.00047	−6	0.036	S-5-F-15	87	3	115.97	4.41	0.00049	−2	0.036
S-5-S-16	16	4	115.30	4.31	0.00048	−4	0.036	S-5-F-16	88	4	114.34	4.40	0.00049	−2	0.036
S-5-S-17	17	5	114.53	4.35	0.00049	−2	0.036	S-5-F-17	89	5	114.72	4.37	0.00049	−2	0.036
S-5-S-18	18	6	115.62	4.30	0.00048	−4	0.036	S-5-F-18	90	6	116.19	4.55	0.00051	+2	0.036
S-5-S-19	19	7	113.49	4.35	0.00049	−2	0.035	S-5-F-19	91	7	114.08	4.48	0.00050	0	0.035
S-5-S-20	20	8	113.51	4.30	0.00048	−4	0.035	S-5-F-20	92	8	116.09	4.42	0.00049	−2	0.036
S-5-S-21	21	9	115.37	4.34	0.00049	−2	0.036	S-5-F-21	93	9	114.97	4.57	0.00051	+2	0.035
S-5-S-22	22	10	113.66	4.31	0.00048	−4	0.035	S-5-F-22	94	10	113.19	4.27	0.00048	−4	0.035
S-5-S-23	23	11	116.88	4.37	0.00048	−2	0.036	S-5-F-23	95	11	113.47	4.25	0.00048	−4	0.035
S-5-S-24	24	12	115.61	4.37	0.00049	−2	0.036	S-5-F-24	96	12	114.39	4.34	0.00049	−2	0.035
S-10-S-1	25	1	121.36	8.25	0.00092	−8	....	S-5-F-25	97	1	114.25	4.37	0.00049	−2	....
S-10-S-2	26	2	120.28	8.35	0.00093	−7	....	S-5-F-26	98	2	113.68	4.35	0.00049	−2	....
S-10-S-3	27	3	119.28	8.45	0.00095	−5	....	S-5-F-27	99	3	116.23	4.50	0.00050	0	....
S-10-S-4	28	4	119.33	8.46	0.00095	−5	....	S-5-F-28	100	4	115.61	4.25	0.00048	−4	....
S-10-S-5	29	5	121.58	8.63	0.00097	−3	....	S-5-F-29	101	5	114.61	4.27	0.00048	−4	....
S-10-S-6	30	6	119.42	8.65	0.00097	−3	....	S-5-F-30	102	6	114.35	4.40	0.00049	−2	....
S-10-S-7	31	7	120.28	8.58	0.00096	−4	....	S-5-F-31	103	7	115.92	4.24	0.00048	−4	....
S-10-S-8	32	8	121.04	8.63	0.00097	−3	....	S-5-F-32	104	8	113.52	4.24	0.00048	−4	....
S-10-S-9	33	9	120.68	8.78	0.00098	−2	....	S-5-F-33	105	9	112.79	4.41	0.00049	−2	....
S-10-S-10	34	10	119.72	8.52	0.00095	−5	....	S-5-F-34	106	10	115.55	4.08	0.00046	−8	....
S-10-S-11	35	11	118.98	8.71	0.00098	−2	....	S-5-F-35	107	11	112.73	4.09	0.00046	−8	....
S-10-S-12	36	12	118.77	8.85	0.00099	−1	....	S-5-F-36	108	12	112.83	4.18	0.00047	−6	....
S-10-S-13	37	1	121.17	8.53	0.00095	−5	0.036	S-7-F-1	109	1	116.06	6.38	0.00072	−4	....
S-10-S-14	38	2	118.57	8.68	0.00097	−3	0.035	S-7-F-2	110	2	115.85	6.32	0.00071	−5	....
S-10-S-15	39	3	120.88	8.64	0.00097	−3	0.036	S-7-F-3	111	3	117.89	6.60	0.00074	−1	....
S-10-S-16	40	4	119.13	8.35	0 00094	−6	0.036	S-7-F-4	112	4	116.97	6.47	0.00072	−4	....
S-10-S-17	41	5	118.84	8.53	0.00095	−5	0.036	S-7-F-5	113	5	118.38	6.45	0.00072	−4	....
S-10-S-18	42	6	118.95	8.68	0.00097	−3	0.036	S-7-F-6	114	6	118.63	6.75	0.00076	+1	....
S-10-S-19	43	7	118.46	8.16	0.00091	−9	0.036	S-7-F-7	115	7	118.40	6.58	0.00074	−1	....
S-10-S-20	44	8	120.59	8.32	0.00093	−7	0.036	S-7-F-8	116	8	113.55	6.50	0.00073	−3	....
S-10-S-21	45	9	121.17	8.40	0.00094	−6	0.036	S-7-F-9	117	9	112.45	6.79	0.00076	+1	....
S-10-S-22	46	10	116.66	8.20	0.00092	−8	0.035	S-7-F-10	118	10	120.49	6.21	0.00070	−7	....
S-10-S-23	47	11	115.05	8.22	0.00092	−8	0.035	S-7-F-11	119	11	117.16	6.31	0.00071	−5	....
S-10-S-24	48	12	120.38	8.22	0.00092	−8	0.036	S-7-F-12	120	12	118.69	6.52	0.00073	−3	....
S-2-F-1	49	1	111.10	2.06	0.00023	−8	....	S-7-F-13	121	1	118.66	7.02	0.00079	+5	0.036
S-2-F-2	50	2	111.80	2.07	0.00023	−8	....	S-7-F-14	122	2	116.07	6.73	0.00075	0	0.036
S-2-F-3	51	3	114.29	2.08	0.00023	−8	....	S-7-F-15	123	3	117.02	6.85	0.00077	+3	0.036
S-2-F-4	52	4	111.99	2.00	0.00022	−12	....	S-7-F-16	124	4	117.01	7.20	0.00080	+7	0.036
S-2-F-5	53	5	112.11	2.04	0.00023	−8	....	S-7-F-17	125	5	119.06	6.99	0.00079	+5	0.036
S-2-F-6	54	6	113.12	2.09	0.00023	−8	....	S-7-F-18	126	6	116.99	7.09	0.00079	+5	0.036
S-2-F-7	55	7	113.85	2.00	0.00022	−12	....	S-7-F-19	127	7	116.96	7.29	0.00081	+8	0.035
S-2-F-8	56	8	112.19	2.05	0.00023	−8	....	S-7-F-20	128	8	119.07	7.09	0.00079	+5	0.035
S-2-F-9	57	9	112.47	2.10	0.00024	−4	....	S-7-F-21	129	9	115.27	7.16	0.00080	+7	0.035
S-5-F-10	58	10	114.62	1.98	0.00022	−12	....	S-7-F-22	130	10	122.84	7.05	0.00079	+5	0.037
S-2-F-11	59	11	114.49	2.05	0.00023	−8	....	S-7-F-23	131	11	121.27	6.90	0.00077	+3	0.037
S-2-F-12	60	12	114.59	2.10	0.00024	−4	....	S-7-F-24	132	12	121.41	6.89	0.00077	+3	0.037
S-2-F-13	61	1	111.25	2.18	0.00024	−4	0.035	S-10-F-1	133	1	118.30	8.53	0.00096	−4	....
S-2-F-14	62	2	112.24	2.20	0.00025	0	0.035	S-10-F-2	134	2	119.49	8.43	0.00094	−6	....
S-2-F-15	63	3	110.70	2.22	0.00025	0	0.035	S-10-F-3	135	3	116.78	8.72	0.00098	−2	....
S-2-F-16	64	4	113.56	2.10	0.00024	−4	0.036	S-10-F-4	136	4	123.23	8.66	0.00097	−3	....
S-2-F-17	65	5	112.20	2.10	0.00024	−4	0.036	S-10-F-5	137	5	119.04	8.61	0.00096	−4	....
S-2-F-18	66	6	112.75	2.15	0.00024	−4	0.036	S-10-F-6	138	6	118.44	8.97	0.00101	+1	....
S-2-F-19	67	7	114.03	2.11	0.00024	−4	0.036	S-10-F-7	139	7	119.35	8.84	0.00099	−1	....
S-2-F-20	68	8	113.58	2.13	0.00024	−4	0.036	S-10-F-8	140	8	118.65	8.81	0.00099	−1	....
S-2-F-21	69	9	114.24	2.17	0.00024	−4	0.036	S-10-F-9	141	9	121.66	9.18	0.00103	+3	....
S-2-F-22	70	10	113.36	2.06	0.00023	−8	0.036	S-10-F-10	142	10	119.01	8.39	0.00094	−6	....
S-2-F-23	71	11	112.91	2.14	0.00024	−4	0.036	S-10-F-11	143	11	117.85	8.42	0.00094	−6	....
S-2-F-24	72	12	113.73	2.15	0.00024	−4	0.036	S-10-F-12	144	12	118.32	8.32	0.00093	−7	....

TABLE III.—DESCRIPTION OF EXPOSURE PANELS (CONTINUED).

Designation Symbol	Panel Number	Position on Plating Rack	Total Weight, g.	Weight of Deposit, g.	Calculated Average Deposit Thickness, in.	Variation from Nominal Thickness, per cent	Average Thickness of Steel, in.	Designation Symbol	Panel Number	Position on Plating Rack	Total Weight, g.	Weight of Deposit, g.	Calculated Average Deposit Thickness, in.	Variation from Nominal Thickness, per cent	Average Thickness of Steel, in.
S-10-F-13	145	1	119.94	8.58	0.00096	−4	0.030	S-20-F-49	217	1	124.65	16.57	0.00186	−7	...
S-10-F-14	146	2	117.09	8.32	0.00093	−7	0.035	S-20-F-50	218	2	125.09	16.61	0.00186	−7	...
S-10-F-15	147	3	117.30	8.48	0.00095	−5	0.035	S-20-F-51	219	3	126.23	17.00	0.00190	−5	...
S-10-F-16	148	4	118.38	8.77	0.00098	−2	0.035	S-20-F-52	220	4	125.75	16.55	0.00185	−8	...
S-10-F-17	149	5	120.29	8.60	0.00096	−4	0.030	S-20-F-53	221	5	128.08	16.74	0.00188	−6	...
S-10-F-18	150	6	120.99	8.80	0.00099	−1	0.030	S-20-F-54	222	6	125.08	17.15	0.00192	−4	...
S-10-F-19	151	7	119.18	8.92	0.00100	0	0.030	S-20-F-55	223	7	124.81	16.55	0.00185	−8	...
S-10-F-20	152	8	120.33	8.74	0.00098	−2	0.030	S-20-F-56	224	8	123.47	16.65	0.00187	−6	...
S-10-F-21	153	9	119.64	8.86	0.00099	−1	0.030	S-20-F-57	225	9	126.59	17.20	0.00193	−4	...
S-10-F-22	154	10	119.34	8.59	0.00096	−4	0.030	S-20-F-58	226	10	123.15	15.62	0.00175	−12	...
S-10-F-23	155	11	118.37	8.49	0.00095	−5	0.035	S-20-F-59	227	11	124.93	15.83	0.00177	−12	...
S-10-F-24	156	12	119.48	8.51	0.00095	−5	0.030	S-20-F-60	228	12	123.84	16.06	0.00180	−10	...
S-10-F-25	157	1	114.86	8.85	0.00099	−1	...	S-20-F-61	229	1	124.54	17.01	0.00191	−5	...
S-10-F-26	158	2	117.99	9.10	0.00102	+2	...	S-20-F-62	230	2	124.35	16.94	0.00190	−5	...
S-10-F-27	159	3	117.00	9.38	0.00105	+5	...	S-20-F-63	231	3	129.67	17.46	0.00196	−2	...
S-10-F-28	160	4	117.29	9.10	0.00102	+2	...	S-20-F-64	232	4	124.43	17.02	0.00191	−5	...
S-10-F-29	161	5	115.86	9.10	0.00103	+3	...	S-20-F-65	233	5	125.06	17.22	0.00193	−4	...
S-10-F-30	162	6	117.28	9.42	0.00106	+6	...	S-20-F-66	234	6	125.30	17.49	0.00196	−2	...
S-10-F-31	163	7	117.03	8.97	0.00101	+1	...	S-20-F-67	235	7	129.88	17.11	0.00192	−4	...
S-10-F-32	164	8	116.18	9.00	0.00101	+1	...	S-20-F-68	236	8	127.44	17.14	0.00192	−4	...
S-10-F-33	165	9	117.00	9.38	0.00105	+5	...	S-20-F-69	237	9	128.35	17.68	0.00198	−1	...
S-10-F-34	166	10	116.52	8.64	0.00097	−3	...	S-20-F-70	238	10	124.38	16.28	0.00183	−9	...
S-10-F-35	167	11	114.40	8.52	0.00096	−4	...	S-20-F-71	239	11	125.37	16.42	0.00184	−8	...
S-10-F-36	168	12	115.93	8.87	0.00100	0	...	S-20-F-72	240	12	127.53	16.71	0.00187	−6	...
S-20-F-1	169	1	123.11	16.68	0.00187	−6	...	C-5-S-1	241	1	120.05	4.79	0.00054	+8	...
S-20-F-2	170	2	123.08	17.23	0.00193	−4	...	C-5-S-2	242	2	115.02	4.87	0.00054	+8	...
S-20-F-3	171	3	127.14	16.62	0.00186	−7	...	C-5-S-3	243	3	115.28	4.92	0.00055	+10	...
S-20-F-4	172	4	128.62	17.01	0.00191	−4	...	C-5-S-4	244	4	113.26	4.82	0.00054	+8	...
S-20-F-5	173	5	126.07	16.65	0.00187	−6	...	C-5-S-5	245	5	113.09	4.92	0.00055	+10	...
S-20-F-6	174	6	127.37	17.02	0.00191	−4	...	C-5-S-6	246	6	114.68	4.89	0.00055	+10	...
S-20-F-7	175	7	125.37	17.32	0.00194	−3	...	C-5-S-7	247	7	113.27	4.91	0.00055	+10	...
S-20-F-8	176	8	126.71	17.01	0.00191	−4	...	C-5-S-8	248	8	114.45	4.97	0.00056	+12	...
S-20-F-9	177	9	125.88	17.42	0.00195	−2	...	C-5-S-9	249	9	112.74	4.97	0.00056	+12	...
S-20-F-10	178	10	127.17	16.54	0.00185	−8	...	C-5-S-10	250	10	111.94	4.89	0.00055	+10	...
S-20-F-11	179	11	124.54	16.36	0.00183	−8	...	C-5-S-11	251	11	118.95	5.02	0.00056	+12	...
S-20-F-12	180	12	128.84	16.62	0.00186	−7	...	C-5-S-12	252	12	114.85	5.00	0.00056	+12	...
S-20-F-13	181	1	124.56	16.51	0.00185	−8	0.035	C-5-S-13	253	1	116.41	4.28	0.00048	−4	0.036
S-20-F-14	182	2	125.90	16.45	0.00184	−8	0.035	C-5-S-14	254	2	114.01	4.35	0.00049	−2	0.035
S-20-F-15	183	3	128.13	17.20	0.00193	−4	0.030	C-5-S-15	255	3	112.54	4.34	0.00049	−2	0.035
S-20-F-16	184	4	128.87	16.87	0.00189	−6	0.030	C-5-S-16	256	4	111.36	4.41	0.00049	−2	0.035
S-20-F-17	185	5	127.57	16.91	0.00189	−6	0.030	C-5-S-17	257	5	114.31	4.51	0.00050	0	0.035
S-20-F-18	186	6	129.63	17.66	0.00198	−1	0.030	C-5-S-18	258	6	112.47	4.47	0.00050	0	0.035
S-20-F-19	187	7	127.70	17.10	0.00192	−4	0.030	C-5-S-19	259	7	112.93	4.54	0.00051	+2	0.035
S-20-F-20	188	8	127.47	17.12	0.00192	−4	0.030	C-5-S-20	260	8	115.08	4.60	0.00052	+4	0.035
S-20-F-21	189	9	129.65	17.87	0.00200	0	0.030	C-5-S-21	261	9	114.92	4.59	0.00051	+2	0.035
S-20-F-22	190	10	125.21	16.32	0.00183	−8	0.035	C-5-S-22	262	10	112.93	4.57	0.00051	+2	0.035
S-20-F-23	191	11	126.60	16.57	0.00185	−8	0.035	C-5-S-23	263	11	115.78	4.68	0.00052	+4	0.036
S-20-F-24	192	12	125.94	16.89	0.00189	−6	0.035	C-5-S-24	264	12	114.29	4.63	0.00052	+4	0.035
S-20-F-25	193	1	126.45	16.45	0.00184	−8	...	C-10-S-1	265	1	115.01	8.13	0.00091	−9	...
S-20-F-26	194	2	127.49	16.33	0.00183	−8	...	C-10-S-2	266	2	119.30	8.36	0.00094	−6	...
S-20-F-27	195	3	127.16	16.95	0.00190	−5	...	C-10-S-3	267	3	119.38	8.35	0.00094	−6	...
S-20-F-28	196	4	127.26	16.62	0.00186	−7	...	C-10-S-4	268	4	116.62	8.41	0.00094	−6	...
S-20-F-29	197	5	125.81	16.64	0.00186	−7	...	C-10-S-5	269	5	119.36	8.61	0.00096	−4	...
S-20-F-30	198	6	129.30	17.35	0.00194	−3	...	C-10-S-6	270	6	113.81	8.54	0.00096	−4	...
S-20-F-31	199	7	128.19	16.86	0.00189	−6	...	C-10-S-7	271	7	119.69	8.66	0.00097	−3	...
S-20-F-32	200	8	126.76	16.94	0.00190	−5	...	C-10-S-8	272	8	117.93	8.84	0.00099	−1	...
S-20-F-33	201	9	128.60	17.66	0.00198	−1	...	C-10-S-9	273	9	119.28	8.89	0.00100	0	...
S-20-F-34	202	10	126.23	16.04	0.00180	−10	...	C-10-S-10	274	10	121.05	8.60	0.00096	−4	...
S-20-F-35	203	11	127.64	16.18	0.00181	−10	...	C-10-S-11	275	11	117.88	8.90	0.00100	0	...
S-20-F-36	204	12	127.71	16.68	0.00187	−6	...	C-10-S-12	276	12	118.92	8.95	0.00100	0	...
S-20-F-37	205	1	124.95	17.99	0.00202	+1	...	C-10-S-13	277	1	117.53	8.72	0.00098	−2	0.035
S-20-F-38	206	2	127.17	16.90	0.00189	−6	...	C-10-S-14	278	2	120.72	8.91	0.00100	0	0.036
S-20-F-39	207	3	128.32	18.19	0.00204	+2	...	C-10-S-15	279	3	119.88	9.04	0.00101	+1	0.036
S-20-F-40	208	4	127.60	18.89	0.00212	+6	...	C-10-S-16	280	4	120.28	8.91	0.00100	0	0.036
S-20-F-41	209	5	127.23	17.99	0.00202	+1	...	C-10-S-17	281	5	124.38	9.23	0.00103	+3	0.037
S-20-F-42	210	6	127.81	18.30	0.00205	+3	...	C-10-S-18	282	6	120.17	9.28	0.00104	+4	0.035
S-20-F-43	211	7	125.33	18.00	0.00202	+1	...	C-10-S-19	283	7	120.35	9.17	0.00103	+3	0.036
S-20-F-44	212	8	125.42	18.02	0.00202	+1	...	C-10-S-20	284	8	121.61	9.44	0.00106	+6	0.036
S-20-F-45	213	9	128.00	18.36	0.00206	+3	...	C-10-S-21	285	9	120.67	9.52	0.00107	+7	0.036
S-20-F-46	214	10	127.18	17.74	0.00199	0	...	C-10-S-22	286	10	117.59	9.19	0.00103	+3	0.035
S-20-F-47	215	11	128.32	17.89	0.00200	0	...	C-10-S-23	287	11	124.63	9.57	0.00107	+7	0.037
S-20-F-48	216	12	124.43	17.14	0.00192	−4	...	C-10-S-24	288	12	119.65	9.61	0.00108	+8	0.035

TABLE III.—DESCRIPTION OF EXPOSURE PANELS (CONTINUED).

Designation Symbol	Panel Number	Position on Plating Rack	Total Weight, g.	Weight of Deposit, g.	Calculated Average Deposit Thickness, in.	Variation from Nominal Thickness, per cent	Average Thickness of Steel, in.
C-2-F-1	289	1	111.48	2.16	0.00024	−4	...
C-2-F-2	290	2	112.65	2.15	0.00024	−4	...
C-2-F-3	291	3	117.91	2.21	0.00025	0	...
C-2-F-4	292	4	118.61	2.20	0.00025	0	...
C-2-F-5	293	5	116.72	2.20	0.00025	0	...
C-2-F-6	294	6	112.09	2.27	0.00025	0	...
C-2-F-7	295	7	112.16	2.24	0.00025	0	...
C-2-F-8	296	8	112.58	2.27	0.00025	0	...
C-2-F-9	297	9	114.07	2.34	0.00026	+4	...
C-2-F-10	298	10	112.42	2.21	0.00025	0	...
C-2-F-11	299	11	112.37	2.22	0.00025	0	...
C-2-F-12	300	12	111.38	2.27	0.00025	0	...
C-2-F-13	301	1	111.26	2.18	0.00024	−4	0.035
C-2-F-14	302	2	113.09	2.14	0.00024	−4	0.036
C-2-F-15	303	3	111.52	2.21	0.00025	0	0.035
C-2-F-16	304	4	110.11	2.19	0.00025	0	0.035
C-2-F-17	305	5	112.36	2.18	0.00024	−4	0.035
C-2-F-18	306	6	112.08	2.26	0.00025	0	0.036
C-2-F-19	307	7	110.69	2.23	0.00025	0	0.035
C-2-F-20	308	8	112.28	2.22	0.00025	0	0.035
C-2-F-21	309	9	115.53	2.32	0.00026	+4	0.035
C-2-F-22	310	10	111.24	2.13	0.00024	−4	0.035
C-2-F-23	311	11	113.94	2.13	0.00024	−4	0.036
C-2-F-24	312	12	113.83	2.17	0.00024	−4	0.036
C-5-F-1	313	1	113.85	4.21	0.00047	−6	...
C-5-F-2	314	2	113.68	4.19	0.00047	−6	...
C-5-F-3	315	3	113.79	4.31	0.00048	−4	...
C-5-F-4	316	4	111.64	4.26	0.00048	−4	...
C-5-F-5	317	5	112.74	4.27	0.00048	−4	...
C-5-F-6	318	6	115.15	4.39	0.00049	−2	...
C-5-F-7	319	7	114.59	4.28	0.00048	−4	...
C-5-F-8	320	8	112.83	4.26	0.00048	−4	...
C-5-F-9	321	9	115.22	4.39	0.00049	−2	...
C-5-F-10	322	10	115.46	4.09	0.00046	−8	...
C-5-F-11	323	11	113.10	4.08	0.00046	−8	...
C-5-F-12	324	12	113.75	4.18	0.00047	−6	...
C-5-F-13	325	1	116.44	4.08	0.00046	−8	0.036
C-5-F-14	326	2	115.02	4.07	0.00046	−8	0.036
C-5-F-15	327	3	113.95	4.16	0.00047	−6	0.036
C-5-F-16	328	4	114.16	3.93	0.00044	−12	0.036
C-5-F-17	329	5	113.39	3.98	0.00045	−10	0.035
C-5-F-18	330	6	116.20	4.07	0.00046	−8	0.036
C-5-F-19	331	7	115.17	3.96	0.00044	−12	0.036
C-5-F-20	332	8	112.84	4.01	0.00045	−10	0.035
C-5-F-21	333	9	112.43	4.10	0.00046	−8	0.035
C-5-F-22	334	10	112.04	3.75	0.00042	−16	0.035
C-5-F-23	335	11	115.02	3.79	0.00042	−16	0.036
C-5-F-24	336	12	111.16	3.81	0.00043	−14	0.035
C-5-F-25	337	1	115.60	4.21	0.00047	−6	...
C-5-F-26	338	2	114.96	4.18	0.00047	−6	...
C-5-F-27	339	3	114.92	4.31	0.00048	−4	...
C-5-F-28	340	4	112.62	4.21	0.00047	−6	...
C-5-F-29	341	5	114.22	4.24	0.00048	−4	...
C-5-F-30	342	6	117.96	4.36	0.00049	−2	...
C-5-F-31	343	7	114.19	4.19	0.00047	−6	...
C-5-F-32	344	8	111.67	4.19	0.00047	−6	...
C-5-F-33	345	9	113.90	4.34	0.00049	−2	...
C-5-F-34	346	10	113.55	4.01	0.00045	−10	...
C-5-F-35	347	11	114.97	4.02	0.00045	−10	...
C-5-F-36	348	12	117.32	4.14	0.00046	−8	...
C-7-F-1	349	1	115.38	6.42	0.00072	−4	...
C-7-F-2	350	2	116.49	6.40	0.00072	−4	...
C-7-F-3	351	3	115.57	6.53	0.00073	−3	...
C-7-F-4	352	4	117.55	6.45	0.00072	−4	...
C-7-F-5	353	5	115.01	6.46	0.00072	−4	...
C-7-F-6	354	6	116.21	6.61	0.00074	−1	...
C-7-F-7	355	7	118.87	6.48	0.00073	−3	...
C-7-F-8	356	8	117.94	6.53	0.00073	−3	...
C-7-F-9	357	9	116.94	6.74	0.00075	0	...
C-7-F-10	358	10	118.59	6.12	0.00069	−8	...
C-7-F-11	359	11	116.00	6.22	0.00070	−7	...
C-7-F-12	360	12	116.61	6.36	0.00071	−5	...
C-7-F-13	361	1	117.15	5.98	0.00067	−11	0.036
C-7-F-14	362	2	116.34	6.03	0.00068	−9	0.035
C-7-F-15	363	3	115.15	6.19	0.00069	−8	0.035
C-7-F-16	364	4	117.24	5.97	0.00067	−11	0.036
C-7-F-17	365	5	117.61	6.08	0.00068	−9	0.036
C-7-F-18	366	6	117.28	6.22	0.00070	−7	0.036
C-7-F-19	367	7	117.27	6.00	0.00067	−11	0.036
C-7-F-20	368	8	114.13	6.06	0.00068	−9	0.035
C-7-F-21	369	9	113.44	6.21	0.00070	−7	0.034
C-7-F-22	370	10	113.70	5.68	0.00064	−15	0.035
C-7-F-23	371	11	116.08	5.75	0.00065	−13	0.035
C-7-F-24	372	12	115.71	5.85	0.00065	−13	0.035
C-10-F-1	373	1	120.02	8.28	0.00093	−7	....
C-10-F-2	374	2	119.61	8.39	0.00094	−6	....
C-10-F-3	375	3	120.14	8.58	0.00096	−4	....
C-10-F-4	376	4	119.24	8.29	0.00093	−7	....
C-10-F-5	377	5	117.42	8.49	0.00095	−5	....
C-10-F-6	378	6	120.78	8.77	0.00098	−2	....
C-10-F-7	379	7	118.12	8.32	0.00093	−7	....
C-10-F-8	380	8	121.15	8.56	0.00096	−4	....
C-10-F-9	381	9	117.70	8.81	0.00099	−1	....
C-10-F-10	382	10	118.96	8.81	0.00099	−1	....
C-10-F-11	383	11	118.61	8.10	0.00091	−9	....
C-10-F-12	384	12	119.13	8.33	0.00093	−7	....
C-10-F-13	385	1	117.68	7.93	0.00089	−11	0.035
C-10-F-14	386	2	120.62	7.98	0.00090	−10	0.036
C-10-F-15	387	3	120.33	8.26	0.00092	−8	0.036
C-10-F-16	388	4	119.42	7.99	0.00090	−10	0.036
C-10-F-17	389	5	117.98	8.09	0.00091	−9	0.035
C-10-F-18	390	6	119.52	8.33	0.00093	−7	0.036
C-10-F-19	391	7	117.38	8.03	0.00090	−10	0.035
C-10-F-20	392	8	116.89	8.12	0.00091	−9	0.035
C-10-F-21	393	9	118.44	8.34	0.00093	−7	0.035
C-10-F-22	394	10	116.21	7.66	0.00086	−14	0.035
C-10-F-23	395	11	118.79	7.75	0.00087	−13	0.035
C-10-F-24	396	12	116.82	7.87	0.00088	−12	0.035
C-10-F-25	397	1	117.80	8.08	0.00091	−9	....
C-10-F-26	398	2	117.59	8.11	0.00091	−9	....
C-10-F-27	399	3	116.71	8.42	0.00094	−6	....
C-10-F-28	400	4	117.82	8.16	0.00092	−8	....
C-10-F-29	401	5	119.35	8.30	0.00093	−7	....
C-10-F-30	402	6	118.80	8.55	0.00096	−4	....
C-10-F-31	403	7	117.53	8.20	0.00092	−8	....
C-10-F-32	404	8	119.05	8.27	0.00093	−7	....
C-10-F-33	405	9	121.30	8.55	0.00096	−4	....
C-10-F-34	406	10	116.06	7.77	0.00087	−13	....
C-10-F-35	407	11	118.97	7.88	0.00088	−12	....
C-10-F-36	408	12	119.28	8.08	0.00090	−10	....
C-20-F-1	409	1	127.56	17.77	0.00199	0	....
C-20-F-2	410	2	126.14	17.37	0.00195	−2	....
C-20-F-3	411	3	127.35	17.86	0.00200	0	....
C-20-F-4	412	4	124.88	17.27	0.00194	−3	....
C-20-F-5	413	5	126.51	17.01	0.00190	−5	....
C-20-F-6	414	6	125.96	17.56	0.00197	−2	....
C-20-F-7	415	7	127.34	17.04	0.00191	−4	....
C-20-F-8	416	8	127.48	16.90	0.00189	−6	....
C-20-F-9	417	9	130.65	17.63	0.00197	−2	....
C-20-F-10	418	10	127.62	16.14	0.00181	−10	....
C-20-F-11	419	11	125.97	16.14	0.00181	−10	....
C-20-F-12	420	12	127.40	16.52	0.00185	−8	....
C-20-F-13	421	1	126.14	16.92	0.00189	−6	0.035
C-20-F-14	422	2	125.57	16.39	0.00184	−8	0.035
C-20-F-15	423	3	123.66	16.77	0.00188	−6	0.035
C-20-F-16	424	4	125.19	16.96	0.00190	−5	0.035
C-20-F-17	425	5	131.54	16.61	0.00186	−7	0.037
C-20-F-18	426	6	129.09	17.00	0.00190	−5	0.036
C-20-F-19	427	7	126.09	16.89	0.00189	−6	0.035
C-20-F-20	428	8	126.19	16.46	0.00184	−8	0.035
C-20-F-21	429	9	125.03	16.93	0.00190	−5	0.035
C-20-F-22	430	10	127.91	16.27	0.00182	−9	0.036
C-20-F-23	431	11	127.58	15.77	0.00177	−12	0.036
C-20-F-24	432	12	126.26	15.99	0.00179	−10	0.036

TABLE III.—DESCRIPTION OF EXPOSURE PANELS (CONTINUED).

Designation Symbol	Panel Number	Position on Plating Rack	Total Weight, g.	Weight of Deposit, g.	Calculated Average Deposit Thickness, in.	Variation from Nominal Thickness, per cent	Average Thickness of Steel, in.	Designation Symbol	Panel Number	Position on Plating Rack	Total Weight, g.	Weight of Deposit, g.	Calculated Average Deposit Thickness, in.	Variation from Nominal Thickness, per cent	Average Thickness of Steel, in.
C-20-F-25	433	1	127.93	16.77	0.00188	−6	...	B-2-F-1	505	1	109.69	2.34	0.00026	+4	....
C-20-F-26	434	2	127.51	16.45	0.00184	−8	...	B-2-F-2	506	2	109.16	2.34	0.00026	+4	....
C-20-F-27	435	3	124.78	16.93	0.00190	−5	...	B-2-F-3	507	3	108.49	2.41	0.00027	+8	....
C-20-F-28	436	4	125.87	16.83	0.00188	−6	...	B-2-F-4	508	4	108.86	2.33	0.00026	+4	....
C-20-F-29	437	5	124.30	16.66	0.00186	−7	...	B-2-F-5	509	5	109.86	2.37	0.00027	+8	....
C-20-F-30	438	6	126.78	17.24	0.00193	−4	...	B-2-F-6	510	6	108.81	2.46	0.00028	+12	....
C-20-F-31	439	7	129.01	16.99	0.00190	−5	...	B-2-F-7	511	7	108.67	2.33	0.00026	+4	....
C-20-F-32	440	8	127.10	16.85	0.00189	−6	...	B-2-F-8	512	8	108.12	2.37	0.00027	+8	....
C-20-F-33	441	9	127.55	17.48	0.00196	−2	...	B-2-F-9	513	9	106.72	2.46	0.00028	+12	....
C-20-F-34	442	10	126.34	16.07	0.00180	−10	...	B-2-F-10	514	10	107.17	2.22	0.00025	0	....
C-20-F-35	443	11	125.70	16.05	0.00180	−10	...	B-2-F-11	515	11	105.34	2.23	0.00025	0	....
C-20-F-36	444	12	127.32	16.48	0.00185	−8	...	B-2-F-12	516	12	106.15	2.28	0.00025	0	....
C-20-F-37	445	1	128.08	16.46	0.00185	−8	...	B-5-F-1	517	1	116.11	4.34	0.00049	−2	....
C-20-F-38	446	2	127.23	16.10	0.00180	−10	...	B-5-F-2	518	2	114.78	4.20	0.00047	−3	....
C-20-F-39	447	3	128.82	16.76	0.00188	−6	...	B-5-F-3	519	3	114.31	4.42	0.00049	−2	....
C-20-F-40	448	4	127.04	16.68	0.00187	−6	...	B-5-F-4	520	4	115.78	4.40	0.00049	−2	....
C-20-F-41	449	5	127.18	16.35	0.00183	−8	...	B-5-F-5	521	5	114.73	4.31	0.00048	−4	....
C-20-F-42	450	6	128.53	16.90	0.00189	−6	...	B-5-F-6	522	6	113.06	4.41	0.00049	−2	....
C-20-F-43	451	7	124.16	16.45	0.00184	−8	...	B-5-F-7	523	7	115.50	4.29	0.00048	−4	....
C-20-F-44	452	8	129.12	16.47	0.00184	−8	...	B-5-F-8	524	8	115.96	4.34	0.00049	−2	....
C-20-F-45	453	9	127.48	16.95	0.00190	−5	...	B-5-F-9	525	9	116.15	4.49	0.00050	0	....
C-20-F-46	454	10	124.77	16.15	0.00181	−6	...	B-5-F-10	526	10	115.75	4.05	0.00045	−10	....
C-20-F-47	455	11	126.75	15.85	0.00177	−12	...	B-5-F-11	527	11	113.39	4.12	0.00046	−8	....
C-20-F-48	456	12	126.36	16.16	0.00181	−10	...	B-5-F-12	528	12	115.23	4.23	0.00047	−6	....
C-20-F-49	457	1	131.31	16.81	0.00189	−6	...	T-1	529		(81.95)[a]	(1.33)	0.00017	....	....
C-20-F-50	458	2	124.84	16.50	0.00185	−8	...	T-2	530		(83.60)	(1.37)	0.00017	....	....
C-20-F-51	459	3	129.54	17.09	0.00191	−4	...	T-3	531		(82.65)	(1.36)	0.00017	....	....
C-20-F-52	460	4	127.51	16.94	0.00190	−5	...	T-4	532		(83.45)	(1.28)	0.00016	....	....
C-20-F-53	461	5	127.41	16.85	0.00188	−6	...	T-5	533		(81.50)	(1.30)	0.00016	....	....
C-20-F-54	462	6	127.70	17.35	0.00194	−3	...	T-6	534		(81.78)	(1.36)	0.00017	....	....
C-20-F-55	463	7	123.75	16.93	0.00190	−5	...	T-7	535	..	(81.95)	(1.39)	0.00017	....	....
C-20-F-56	464	8	126.90	16.95	0.00190	−5	...	T-8	536	..	(82.60)	(1.34)	0.00017	....	....
C-20-F-57	465	9	126.52	17.65	0.00198	−1	...	T-9	537	..	(79.85)	(1.34)	0.00017	....	....
C-20-F-58	466	10	126.68	16.33	0.00183	−8	...	T-10	538	..	(79.47)	(1.33)	0.00017	....	....
C-20-F-59	467	11	129.26	16.40	0.00184	−8	...	T-11	539	..	(77.36)	(1.28)	0.00016	....	....
C-20-F-60	468	12	130.56	16.79	0.00188	−6	...	T-12	540		(80.64)	(1.22)	0.00015	....	....
C-20-F-61	469	1	126.24	16.78	0.00188	−6	...	A-1	541	..	(107.40)	(2.94)	0.00032	....	....
C-20-F-62	470	2	127.76	16.68	0.00187	−6	...	A-2	542	..	(107.04)	(3.04)	0.00036	....	....
C-20-F-63	471	3	128.82	17.25	0.00193	−4	...	A-3	543	..	(107.16)	(3.36)	0.00038	....	....
C-20-F-64	472	4	130.01	16.91	0.00190	−5	...	A-4	544	..	(107.16)	(3.22)	0.00036	....	....
C-20-F-65	473	5	128.67	16.89	0.00189	−6	...	A-5	545	..	(107.04)	(3.07)	0.00036	....	....
C-20-F-66	474	6	129.79	17.56	0.00196	−2	...	A-6	546	..	(107.40)	(3.29)	0.00038	....	....
C-20-F-67	475	7	125.80	17.07	0.00191	−4	...	A-7	547	..	(106.20)	(3.32)	0.00038	....	....
C-20-F-68	476	8	128.52	17.15	0.00192	−4	...	A-8	548	..	(107.76)	(3.62)	0.00041	....	....
C-20-F-69	477	9	128.39	17.86	0.00200	0	...	A-9	549	..	(107.88)	(3.50)	0.00040	....	....
C-20-F-70	478	10	124.36	16.18	0.00181	−10	...	A-10	550	..	(107.40)	(3.25)	0.00037	....	....
C-20-F-71	479	11	127.09	16.41	0.00184	−8	...	A-11	551	..	(106.32)	(3.25)	0.00037	....	....
C-20-F-72	480	12	127.00	16.81	0.00188	−6	...	A-12	552	..	(106.44)	(3.31)	0.00038	....	....
B-2-S-1	481	1	114.19	2.07	0.00023	−8	...	G-2-1	577	..	109.73	1.10	0.00020	0	....
B-2-S-2	482	2	112.28	2.16	0.00024	−4	...	G-2-2	578	..	111.34	1.07	0.00019	−5	....
B-2-S-3	483	3	110.92	2.16	0.00024	−4	...	G-2-3	579	..	112.62	1.09	0.00019	−5	....
B-2-S-4	484	4	113.10	2.07	0.00023	−8	...	G-2-4	580	..	110.65	1.09	0.00019	−5	....
B-2-S-5	485	5	112.91	2.12	0.00024	−4	...	G-2-5	581	..	110.78	1.07	0.00019	−5	....
B-2-S-6	486	6	112.49	2.11	0.00024	−4	...	G-2-6	582	..	110.06	1.07	0.00019	−5	....
B-2-S-7	487	7	112.61	2.09	0.00023	−8	...	G-2-7	583	..	111.32	1.09	0.00019	−5	....
B-2-S-8	488	8	112.47	2.08	0.00023	−8	...	G-2-8	584	..	113.01	1.09	0.00019	−5	....
B-2-S-9	489	9	113.52	2.07	0.00023	−8	...	G-2-9	585	..	113.05	1.17	0.00021	+5	....
B-2-S-10	490	10	112.90	2.10	0.00024	−4	...	G-2-10	586	..	111.09	1.05	0.00019	−5	....
B-2-S-11	491	11	112.77	2.09	0.00023	−8	...	G-2-11	587	..	109.03	1.07	0.00019	−5	....
B-2-S-12	492	12	111.46	2.15	0.00024	−4	...	G-2-12	588	..	109.31	1.05	0.00019	−5	....
B-5-S-1	493	1	115.66	4.22	0.00047	−6	...	G-10-1	589	..	(106.32)	(5.36)	0.00084	+12	....
B-5-S-2	494	2	116.85	4.60	0.00052	+4	...	G-10-2	590	..	(107.52)	(4.43)	0.00078	+4	....
B-5-S-3	495	3	116.74	4.65	0.00052	+4	...	G-10-3	591	..	(108.36)	(4.54)	0.00079	+5	....
B-5-S-4	496	4	115.58	4.24	0.00047	−6	...	G-10-4	592	..	(107.16)	(4.50)	0.00079	+5	....
B-5-S-5	497	5	116.79	4.66	0.00052	+4	...	G-10-5	593	..	(106.32)	(4.62)	0.00082	+9	....
B-5-S-6	498	6	116.84	4.64	0.00052	+4	...	G-10-6	594	..	(107.04)	(4.51)	0.00079	+5	....
B-5-S-7	499	7	113.55	4.23	0.00047	−6	...	G-10-7	595	..	(106.44)	(4.75)	0.00084	+12	....
B-5-S-8	500	8	115.36	4.56	0.00051	+2	...	G-10-8	596	..	(107.52)	(4.57)	0.00080	+7	....
B-5-S-9	501	9	113.72	4.61	0.00052	+4	...	G-10-9	597	..	(109.08)	(4.66)	0.00081	+8	....
B-5-S-10	502	10	112.18	4.22	0.00047	−6	...	G-10-10	598	..	(107.28)	(4.58)	0.00081	+8	....
B-5-S-11	503	11	111.66	4.46	0.00050	0	...	G-10-11	599	..	(105.72)	(4.58)	0.00081	+8	....
B-5-S-12	504	12	115.61	4.65	0.00052	+4	...	G-10-12	600	..	(107.40)	(4.61)	0.00081	+8	....

---

[a] Numbers in parentheses calculated from average of four adjacent 1 by 2-in. specimens.

TABLE III.—DESCRIPTION OF EXPOSURE PANELS (CONTINUED).

Designation Symbol	Panel Number	Position on Plating Rack	Total Weight, g.	Weight of Deposit, g.	Calculated Average Deposit Thickness, in.	Variation from Nominal Thickness, per cent	Average Thickness of Steel, in.	Designation Symbol	Panel Number	Position on Plating Rack	Total Weight, g.	Weight of Deposit, g.	Calculated Average Deposit Thickness, in.	Variation from Nominal Thickness, per cent	Average Thickness of Steel, in.
0-1	601	..	111.14	...	...	...	0.036	S-2-F-1	673	1	112.13	2.13	0.00024	−4	0.035
0-2	602	..	110.99	...	...	...	0.036	S-2-F-2	674	2	110.35	2.10	0.00024	−4	0.035
0-3	603	..	110.18	...	...	...	0.036	S-2-F-3	675	3	109.96	2.12	0.00024	−4	0.035
0-4	604	..	111.32	...	...	...	0.036	S-2-F-4	676	4	110.51	2.06	0.00023	−8	0.035
0-5	605	..	115.28	...	...	...	0.037	S-2-F-5	677	5	112.82	2.06	0.00023	−8	0.036
0-6	606	..	115.15	...	...	...	0.037	S-2-F-6	678	6	111.73	2.02	0.00023	−8	0.035
0-7	607	..	115.10	...	...	...	0.037	S-2-F-7	679	7	113.25	2.03	0.00023	−8	0.036
0-8	608	..	114.99	...	...	...	0.037	S-2-F-8	680	8	112.48	2.04	0.00023	−8	0.036
0-9	609	..	110.83	...	...	...	0.036	S-2-F-9	681	9	111.11	2.12	0.00024	−4	0.036
0-10	610	..	110.93	...	...	...	0.036	S-2-F-10	682	10	111.20	2.18	0.00025	0	0.035
0-11	611	..	115.45	...	...	...	0.037	S-2-F-11	683	11	113.10	2.01	0.00022	−12	0.036
0-12	612	..	112.00	...	...	...	0.036	S-2-F-12	684	12	112.13	2.07	0.00023	−8	0.036
0-13	613	..	115.67	...	...	...	0.037	S-5-F-1	685	1	114.16	4.06	0.00045	−10	0.035
0-14	614	..	115.33	...	...	...	0.037	S-5-F-2	686	2	113.50	4.52	0.00050	0	0.035
0-15	615	..	115.24	...	...	...	0.037	S-5-F-3	687	3	115.54	4.07	0.00046	−8	0.036
0-16	616	..	115.18	...	...	...	0.037	S-5-F-4	688	4	114.76	4.06	0.00045	−10	0.036
0-17	617	..	110.66	...	...	...	0.036	S-5-F-5	689	5	114.67	4.06	0.00045	−10	0.036
0-18	618	..	111.97	...	...	...	0.036	S-5-F-6	690	6	114.88	4.11	0.00046	−8	0.036
0-19	619	..	110.60	...	...	...	0.036	S-5-F-7	691	7	114.79	4.06	0.00045	−10	0.036
0-20	620	..	110.35	...	...	...	0.036	S-5-F-8	692	8	114.87	4.16	0.00046	−8	0.036
0-21	621	..	108.95	...	...	...	0.035	S-5-F-9	693	9	114.89	4.27	0.00048	−4	0.036
0-22	622	..	115.14	...	...	...	0.037	S-5-F-10	694	10	115.45	4.06	0.00045	−10	0.036
0-23	623	..	111.78	...	...	...	0.036	S-5-F-11	695	11	113.28	4.14	0.00046	−8	0.035
0-24	624	..	111.50	...	...	...	0.036	S-5-F-12	696	12	115.59	4.22	0.00047	−6	0.036
S-10-A2-1	625	1	115.54	7.99	0.00090	−10	...	S-7-F-1	697	1	117.26	6.13	0.00069	−8	0.036
S-10-A2-2	626	2	117.17	7.85	0.00089	−11	...	S-7-F-2	698	2	115.30	6.24	0.00070	−7	0.035
S-10-A2-3	627	3	116.82	8.14	0.00092	−8	...	S-7-F-3	699	3	116.81	6.24	0.00070	−7	0.036
S-10-A2-4	628	4	119.83	8.21	0.00093	−7	...	S-7-F-4	700	4	116.31	6.16	0.00069	−8	0.036
S-10-A2-5	629	5	120.09	7.94	0.00090	−10	...	S-7-F-5	701	5	117.38	6.39	0.00072	−4	0.036
S-10-A2-6	630	6	118.71	8.21	0.00093	−7	...	S-7-F-6	702	6	116.75	6.49	0.00073	−3	0.036
S-10-A2-7	631	7	117.44	8.41	0.00095	−5	...	S-7-F-7	703	7	117.38	6.37	0.00071	−5	0.036
S-10-A2-8	632	8	118.80	8.15	0.00092	−8	...	S-7-F-8	704	8	117.09	6.45	0.00072	−4	0.036
S-10-A2-9	633	9	120.17	8.51	0.00096	−4	...	S-7-F-9	705	9	118.06	6.73	0.00075	0	0.036
S-10-A2-10	634	10	119.22	8.29	0.00094	−6	...	S-7-F-10	706	10	116.38	6.09	0.00068	−9	0.036
S-10-A2-11	635	11	118.77	8.29	0.00094	−6	...	S-7-F-11	707	11	116.10	6.40	0.00072	−4	0.036
S-10-A2-12	636	12	116.63	8.54	0.00097	−3	...	S-7-F-12	708	12	118.40	6.56	0.00074	−1	0.036
S-10-A2-13	637	1	117.33	7.80	0.00088	−12	...	S-10-F-1	709	1	120.19	8.46	0.00095	−5	0.036
S-10-A2-14	638	2	117.70	7.72	0.00087	−13	...	S-10-F-2	710	2	118.24	8.53	0.00096	−4	0.036
S-10-A2-15	639	3	119.52	8.20	0.00093	−7	...	S-10-F-3	711	3	117.00	8.43	0.00094	−6	0.036
S-10-A2-16	640	4	118.85	8.05	0.00091	−9	...	S-10-F-4	712	4	120.47	8.53	0.00096	−4	0.036
S-10-A2-17	641	5	117.26	7.90	0.00089	−11	...	S-10-F-5	713	5	117.74	8.76	0.00098	−2	0.035
S-10-A2-18	642	6	120.01	8.34	0.00094	−6	...	S-10-F-6	714	6	119.34	8.78	0.00098	−2	0.036
S-10-A2-19	643	7	117.57	8.21	0.00093	−7	...	S-10-F-7	715	7	121.03	8.76	0.00098	−2	0.036
S-10-A2-20	644	8	118.80	8.04	0.00091	−9	...	S-10-F-8	716	8	118.99	8.92	0.00100	0	0.035
S-10-A2-21	645	9	119.25	8.47	0.00096	−4	...	S-10-F-9	717	9	115.93	8.20	0.00092	−8	0.035
S-10-A2-22	646	10	118.75	8.16	0.00092	−8	...	S-10-F-10	718	10	116.93	8.49	0.00095	−5	0.035
S-10-A2-23	647	11	118.65	8.17	0.00092	−8	...	S-10-F-11	719	11	118.91	8.75	0.00098	−2	0.036
S-10-A2-24	648	12	118.54	8.58	0.00097	−3	...	S-10-F-12	720	12	118.13	8.80	0.00099	−1	0.035
S-10-A10-1	649	1	125.04	8.89	0.00104	+4	...	S-20-F-1	721	1	123.94	15.98	0.00179	−10	0.035
S-10-A10-2	650	2	115.12	8.62	0.00101	+1	...	S-20-F-2	722	2	125.18	16.04	0.00180	−10	0.035
S-10-A10-3	651	3	120.85	8.90	0.00104	+4	...	S-20-F-3	723	3	124.40	16.19	0.00181	−10	0.035
S-10-A10-4	652	4	121.40	8.19	0.00096	−4	...	S-20-F-4	724	4	126.18	17.56	0.00186	−7	0.035
S-10-A10-5	653	5	120.62	8.08	0.00095	−5	...	S-20-F-5	725	5	127.44	16.36	0.00184	−8	0.036
S-10-A10-6	654	6	121.62	8.32	0.00097	−3	...	S-20-F-6	726	6	124.30	16.68	0.00187	−6	0.035
S-10-A10-7	655	7	118.61	8.47	0.00099	−1	...	S-20-F-7	727	7	126.78	16.82	0.00188	−6	0.035
S-10-A10-8	656	8	118.94	8.15	0.00095	−5	...	S-20-F-8	728	8	126.96	16.57	0.00186	−7	0.036
S-10-A10-9	657	9	119.68	8.55	0.00100	0	...	S-20-F-9	729	9	123.49	16.08	0.00180	−10	0.035
S-10-A10-10	658	10	119.94	8.57	0.00100	0	...	S-20-F-10	730	10	125.16	15.98	0.00179	−10	0.035
S-10-A10-11	659	11	118.76	8.21	0.00096	−4	...	S-20-F-11	731	11	124.85	16.98	0.00190	−5	0.035
S-10-A10-12	660	12	119.10	8.41	0.00099	−1	...	S-20-F-12	732	12	126.86	16.46	0.00184	−8	0.036
S-10-A10-13	661	1	119.92	8.56	0.00100	0	...	S-5-S-1	733	1	113.82	4.14	0.00046	−8	0.035
S-10-A10-14	662	2	119.34	8.41	0.00099	−1	...	S-5-S-2	734	2	113.65	4.05	0.00045	−10	0.035
S-10-A10-15	663	3	116.62	8.69	0.00102	+2	...	S-5-S-3	735	3	115.94	4.09	0.00046	−8	0.036
S-10-A10-16	664	4	118.19	9.00	0.00105	+5	...	S-5-S-4	736	4	115.67	4.12	0.00046	−8	0.036
S-10-A10-17	665	5	119.27	8.95	0.00105	+5	...	S-5-S-5	737	5	114.60	4.05	0.00045	−10	0.036
S-10-A10-18	666	6	120.81	8.96	0.00105	+5	...	S-5-S-6	738	6	113.26	4.05	0.00045	−10	0.035
S-10-A10-19	667	7	119.84	8.15	0.00096	−4	...	S-5-S-7	739	7	114.58	4.06	0.00045	−10	0.036
S-10-A10-20	668	8	119.31	9.00	0.00105	+5	...	S-5-S-8	740	8	114.43	4.13	0.00046	−8	0.036
S-10-A10-21	669	9	117.42	8.21	0.00096	−4	...	S-5-S-9	741	9	114.12	4.18	0.00047	−6	0.036
S-10-A10-22	670	10	119.12	8.17	0.00096	−4	...	S-5-S-10	742	10	114.54	4.12	0.00046	−8	0.036
S-10-A10-23	671	11	118.46	8.99	0.00105	+5	...	S-5-S-11	743	11	110.87	4.19	0.00047	−6	0.035
S-10-A10-24	672	12	118.14	8.19	0.00096	−4	...	S-5-S-12	744	12	114.31	4.20	0.00047	−6	0.036

TABLE III.—DESCRIPTION OF EXPOSURE PANELS (CONTINUED).

Designation Symbol	Panel Number	Position on Plating Rack	Total Weight, g.	Weight of Deposit, g.	Calculated Average Deposit Thickness, in.	Variation from Nominal Thickness, per cent	Average Thickness of Steel, in.
S-10-S-1	745	1	118.16	8.02	0.00090	+6	0.036
S-10-S-2	746	2	122.31	8.39	0.00094	+10	0.037
S-10-S-3	747	3	117.67	8.59	0.00096	+13	0.035
S-10-S-4	748	4	116.88	8.30	0.00093	+9	0.035
S-10-S-5	749	5	117.75	8.64	0.00097	+14	0.036
S-10-S-6	750	6	116.91	8.05	0.00090	+6	0.035
S-10-S-7	751	7	117.30	8.53	0.00096	+12	0.035
S-10-S-8	752	8	116.56	8.05	0.00090	+6	0.035
S-10-S-9	753	9	119.85	8.16	0.00092	+8	0.036
S-10-S-10	754	10	118.69	8.56	0.00096	+12	0.036
S-10-S-11	755	11	116.91	8.03	0.00090	+6	0.035
S-10-S-12	756	12	117.09	8.16	0.00092	+8	0.035
S-08-F-1	757	1	114.562	0.674	0.000075	−12	...
S-08-F-2	758	2	111.948	0.683	0.000077	−9	...
S-08-F-3	759	3	112.253	0.700	0.000078	−8	...
S-08-F-4	760	4	110.805	0.670	0.000075	−12	...
S-08-F-5	761	5	109.528	0.684	0.000077	−9	...
S-08-F-6	762	6	109.707	0.709	0.000079	−7	...
S-08-F-7	763	7	110.427	0.678	0.000076	−11	...
S-08-F-8	764	8	109.128	0.710	0.000080	−6	...
S-08-F-9	765	9	113.172	0.736	0.000083	−2	...
S-08-F-10	766	10	111.308	0.676	0.000076	−11	...
S-08-F-11	767	11	111.585	0.684	0.000077	−9	...
S-08-F-12	768	12	110.252	0.710	0.000080	−6	...
S-08-F-13	769	1	109.585	0.714	0.000080	−6	...
S-08-F-14	770	2	108.880	0.727	0.000082	−4	...
S-08-F-15	771	3	110.007	0.747	0.000084	−1	...
S-08-F-16	772	4	111.425	0.716	0.000080	−6	...
S-08-F-17	773	5	110.304	0.734	0.000082	−4	...
S-08-F-18	774	6	111.860	0.767	0.000086	+1	...
S-08-F-19	775	7	110.988	0.736	0.000083	−2	...
S-08-F-20	776	8	112.052	0.769	0.000086	+1	...
S-08-F-21	777	9	110.201	0.775	0.000087	+2	...
S-08-F-22	778	10	108.489	0.756	0.000085	0	...
S-08-F-23	779	11	112.228	0.737	0.000083	−2	...
S-08-F-24	780	12	111.075	0.775	0.000087	+2	...
C-08-F-1	781	1	114.682	0.874	0.000098	+15	...
C-08-F-2	782	2	111.096	0.873	0.000098	+15	...
C-08-F-3	783	3	110.792	0.890	0.000100	+17	...
C-08-F-4	784	4	108.412	0.894	0.000100	+17	...
C-08-F-5	785	5	112.393	0.915	0.000103	+21	...
C-08-F-6	786	6	111.950	0.935	0.000105	+23	...
C-08-F-7	787	7	111.015	0.912	0.000102	+20	...
C-08-F-8	788	8	111.151	0.934	0.000105	+23	...
C-08-F-9	789	9	110.540	0.937	0.000105	+23	...
C-08-F-10	790	10	113.629	0.877	0.000098	+15	...
C-08-F-11	791	11	113.376	0.904	0.000101	+19	...
C-08-F-12	792	12	113.289	0.946	0.000106	+25	...
C-08-F-13	793	1	112.958	0.790	0.000089	+5	...
C-08-F-14	794	2	108.351	0.800	0.000090	+6	...
C-08-F-15	795	3	112.355	0.827	0.000093	+9	...
C-08-F-16	796	4	109.547	0.814	0.000091	+7	...
C-08-F-17	797	5	111.325	0.832	0.000093	+9	...
C-08-F-18	798	6	111.435	0.866	0.000097	+14	...
C-08-F-19	799	7	112.248	0.823	0.000092	+8	...
C-08-F-20	800	8	112.805	0.853	0.000096	+13	...
C-08-F-21	801	9	113.945	0.878	0.000099	+16	...
C-08-F-22	802	10	110.658	0.797	0.000090	+6	...
C-08-F-23	803	11	106.968	0.823	0.000092	+8	...
C-08-F-24	804	12	110.622	0.876	0.000098	+15	...

were lead plated $\frac{1}{8}$ in. in from the edge in order to prevent edge rusting.

Four vertical bare strips $\frac{1}{16}$, $\frac{1}{8}$, $\frac{1}{4}$ and $\frac{1}{2}$ in. wide are left on certain of the plated panels for the purpose of determining possible galvanic effects and possible creeepage of rust under the lead plate. This was accomplished by spraying a synthetic resin lacquer through a suitable mask, electroplating, and then peeling off the lacquer. These panels are designated as "damaged."

IDENTIFICATION OF THE PANELS

Each panel carries a specimen number and a designation, as shown in Table II. For the plated panels, the first letter of the designation indicates the base on which the lead is plated, and the first number shows the nominal plate thickness in ten-thousandths of an inch. The next letter defines the plating bath, and the final number, the position which the panel occupied on the plating rack.

DESCRIPTION OF COATINGS

Data for all of the panels are given in Table III. These include the total weight of the plated panel, the weight of deposit, the calculated average coating thickness, the percentage variation from the nominal thickness, and, for those specimens to be examined for loss in tensile properties, the thickness of the steel base.

The plating rack and anodes were so arranged that the average coating thickness, as measured by increase in weight, on any one of the twelve panels plated simultaneously varies no more than 5 per cent from the mean average thickness of the twelve. For the most part, deviations from the nominal thickness are less than 10 per cent, although in a few instances the deviations are somewhat greater. The plate thickness over any single panel, as measured with the Magnegage and by electrolytic stripping of small areas over the panel surface, varies less than 5 per cent to within $\frac{1}{4}$ in. of the edges for all of the plates so measured. The variation in plate thickness on the two faces of any individual panel is less than 10 per cent.

The thickness of the copper plate, where present, is in all cases 0.000015 in.

The coating thickness on the galvanized sheet was determined by stripping in an inhibited hydrochloric acid solution, and that of the hot-dipped lead alloys by anodic stripping at 20 amp. per sq. ft. in a solution of sodium hydroxide, sodium metasilicate, and Rochelle salt.

The hot-dipped lead alloy coating, designated by the letter T, analyzed 18.9 per cent tin, balance lead, and the alloy coating designated by A analyzed 2.35 per cent tin, and 2.45 per cent antimony, balance lead.

DISTRIBUTION OF THE PANELS

As previously indicated, the plating of the specimens was carried out on racks holding twelve panels each in four rows and three columns. Positions on the plating rack were numbered horizontally from left to right. Three panels from each rack were assigned to each of the four exposure stations. To take into account possible but unknown differences that might have been due to the effect of position on the plating rack, assignment to the four stations was made on the basis of a modified Latin square (Fisher, "Design of Experiments"). By this arrangement, panels plated in positions 1, 8, and 12 were assigned to New York, 2, 6, and 7 to State College, 3, 5, and 10 to Kure Beach, and 4, 9, and 11 to Tela, Honduras.

The racks at the four stations hold the specimens at an angle of 30 deg. from the horizontal, facing south, in five horizontal rows of thirty columns. Each panel carries a number (see Table III) corresponding to its position in a rational listing. To insure random distribution on the exposure racks, the samples at a given station were listed by sample number and then assigned a second number defining the position on the exposure rack. The latter number was taken from a random number list (Tippett's Random Number Tables).

INSPECTION DATA

Panels were exposed at New York on January 11, 1944, at State College on February 19, 1944, and at Kure Beach on January 18, 1944. Exposure will be started at Tela in the near future.

Electroplated lead coatings exposed to the atmosphere first either darken in appearance or acquire a film of a white corrosion product. The first evidence of attack on the steel base appears in the form of pinhole rust spots, which may occur in groups or colonies or which may be uniformly distributed over the panel surface. On further exposure, the pinhole rust spots either disappear or merge into measurable rust areas. Rust stains that are not directly related to attack on the steel at the point of their appearance may be disregarded. It is the intention of the Inspection Group to report periodically on these conditions as they occur on the panels.

Table IV describes the condition of those panels which had shown evidence of rusting at the time of last inspection.

At New York, after 0.18 yr. exposure, the specimens were generally dark on the upper surface and somewhat lighter with mottled white corrosion product on the under surface. At State College and at Kure Beach the lead-coated panels were irregularly covered with a white corro-

TABLE IV.—CONDITION OF PANELS SHOWING EVIDENCE OF RUST.

Abbreviations and Symbols Used: D—darkening of coating; W—white corrosion film; P—number of pinholes, up to 25, visible at normal reading distance; IP—pinholes, more than 25, irregularly distributed; RP—pinholes, more than 25, distributed uniformly; R—per cent apparent rust of base metal.

Coating Group	Nominal Coating Thickness (in.)	Number of Panels Inspected at Each Station	New York, N. Y.					State College, Pa.			Kure Beach, N. C.		
			Panel Number	Upper Surface		Under Surface		Panel Number	Upper Surface	Under Surface	Panel Number	Upper Surface	Under Surface
				0.07 yr.	0.18 yr.	0.07 yr.	0.18 yr.		0.07 yr.	0.07 yr.		0.14 yr.	0.14 yr.
Sulfamate lead on steel	0.00050	5	15									W	W-1R
Fluoborate lead on steel	0.00008	3	769	D-RP	60R	...	40R	...	...	...	771	97R	99R
			776	D-RP	30R	...	25R	...	...	...	773	95R	95R
			780		40R	...	35R	...	...	...	778	98R	90R
Fluoborate lead on steel	0.00025	5	49		D-IP	...	D-IP	...	...	...	51	W-RP	W-5R
			56		D-IP	...	D-IP	...	...	...	53	W-RP	W-2R
			60		D-IP	...	D-IP	...	...	...	58	W-RP	W-3R
			61		D-3P	...	D-IP	...	...	...	63	10 R	...
			72		D-IP		D-IP						
Fluoborate lead on steel	0.00050	5	73		3P		...				87	W-IP	...
			85		1P		...						
Fluoborate lead on steel (damaged)	0.00100	3	164		D-3P		D-6P						
Fluoborate lead on steel	0.00200	17	228		D-7P		...						
Fluoborate lead on copper plated steel	0.00008	3	793	...	50R	...	45R	794	RP	10P	795	90R	100R
			800	D-RP	30R	...	20R	798	RP	2P	797	60R	100R
			804	D-RP	50R	...	40R	799	RP	5P	802	75R	85R
Fluoborate lead on copper-plated steel	0.00025	5	301		...		10P				293	...	WRP
											303	...	10R
											310	...	25R
Fluoborate lead on copper-plated steel (damaged)	0.00050	3	348		D-IP		...						
Fluoborate lead on copper-plated steel	0.00075	5	360		D-IP		...						
Fluoborate lead on copper-plated steel (damaged)	0.00100	3	404		D-5P		...						
Sulfamate lead-tin (2 per cent tin) on steel	0.00100	3						626	D-1P		627	IP	IP
											629	IP	IP
											634	IP	IP
Sulfamate lead-tin (10 per cent tin) on steel	0.00100	3									651	IP	...
											653	IP	IP
											658	IP	...
Commercial hot-dipped Terne (20 per cent tin)	0.00017	3	529	D-RP	D-IP	...	D-IP	530	80R	IP	531	IP	IP
			536	D-RP	3R	...	2R	534	15R	2R	533	80R	10R
			540	D-IP	5R	...	5R	535	50R	IP	538	99R	10R
Commercial hot-dipped lead (2.5 per cent tin, 2 per cent antimony)	0.00040	3	541	5R	10R	...	15R	542	10R	IP	543	40R	40R
			548	5R	5R	...	5R	546	20R	10R	545	70R	35R
			552	...	10R	...	15R	547	10R	10R	550	70R	50R
Bare steel		6	601	100R	100R	100R	100R	602	50R	90R	603	100R	100R
			608	100R	100R	100R	100R	606	70R	95R	605	100R	100R
			612	100R	100R	100R	100R	607	40R	95R	610	100R	100R
			613	100R	100R	100R	100R	614	45R	95R	615	100R	100R
			620	100R	100R	100R	100R	618	50R	95R	617	100R	100R
			624	100R	100R	100R	100R	619	35R	95R	622	100R	100R

sion film (less pronounced on the under surface) with the exception of the alloyed coatings, either hot-dipped or electroplated, which had darkened.

It is evident from Table IV that the 0.00008-in. electroplated lead and the hot-dipped lead alloy coatings have suffered early and severe rusting, the extent of which varies with the atmospheres.

At State College after 0.07 yr. the 0.00008-in. lead plates over copper plate had turned a purplish-red color on both the upper and under surfaces and were quite different in appearance from panels without copper plate and from similar panels at the other stations. Under the conditions existing at State College, the copper undercoat appears to be detrimental to the very thin lead plates.

No creeping of rust under the lead plating at the bare steel-lead interfaces on the "damaged" panels has occurred at any of the stations.

The subcommittee feels that any broad conclusions regarding the utility of electroplated lead coatings on steel are unwarranted at this early stage of the tests.

Respectfully submitted on behalf of the subcommittee,

H. A. PRAY,
Chairman.

REPORT OF COMMITTEE B-9
ON
METAL POWDERS AND METAL POWDER PRODUCTS

The formation of a standing committee on metal powders and metal powder products resulted from numerous suggestions to the Society that standardization was needed in this field, particularly to cover satisfactory methods of evaluating essential properties of both the powders and the resulting compacts. The members of the Society in the Buffalo area sponsored a Symposium on Powder Metallurgy, in Buffalo, N. Y., on March 3, 1943, with a resulting publication,[1] comprising the papers and discussion presented at the symposium. In view of the interest shown and in response to requests that work in this field be undertaken, a special study committee which met in New York, N. Y., on July 22, 1943, under the chairmanship of J. R. Townsend, reviewed the situation and recommended to the Executive Committee that a standing committee on powder metallurgy be organized, which recommendation was approved, with the following scope of activities:

> *Scope.*—The formulation of specifications and methods of test for metal powders and metal powder products.

W. A Reich, General Electric Co., and W. R. Toeplitz, Bound Brook Oil-Less Bearing Co., were appointed temporary chairman and temporary secretary, respectively, and an organization meeting was held in New York, N. Y., on February 22, 1944.

The temporary officers were elected as permanent chairman and secretary for one year.

The personnel of the committee, classified as indicated in the list appearing in the 1944 A.S.T.M. Year Book, was approved. In order to cover adequately the various phases of powder metallurgy, the following subcommittee structure was approved:

Subcommittee I on Nomenclature and Technical Data (F. N. Rhines, chairman) will first prepare a compilation of definitions of terms peculiar to powder metallurgy; then assemble such fundamental data on metal powders and metal powder products as may fall outside the provinces of the other subcommittees.

Subcommittee II on Metal Powders (D. O. Noel, chairman) will prepare methods of test and specifications for metal powders.

Subcommittee III on Metal Powder Products (R. P. Koehring, chairman) will prepare methods of test and specifications for metal powder products. Due to the diversity of products under this subcommittee's jurisdiction, the following subsections were approved:

Subsection:

1. Bearings, D. S. Urquhart, *chairman.*
2. Structural Parts, F. V. Lenel, *chairman.*
3. Cemented Carbides, E. W. Engle, *chairman.*
4. Friction Materials, J. R. Nurney, *chairman.*
5. Electrical Parts, A. B. Gibson, *chairman.*

A temporary advisory committee was named consisting of the officers of Committee B-9 and the subcommittee chairmen.

---

[1] Symposium on Powder Metallurgy, Am. Soc. Testing Mats. (1943). (Symposium issued as separate publication.)

A subcommittee, consisting of B. T. du Pont, chairman, P. R. Kalischer, and A. B. Gibson, was appointed to prepare proposed by-laws of Committee B-9 for approval by the committee.

It was emphasized at the organization meeting that Committee B-9 will cooperate with committees of other societies engaged in powder metallurgy activity and with other A.S.T.M. committees having overlapping interests.

Respectfully submitted on behalf of the committee,

W. A. REICH,
Chairman.

W. R. TOEPLITZ,
Secretary.

REPORT OF COMMITTEE C-1

ON

CEMENT

Committee C-1 on Cement held two meetings during the past year: one in Pittsburgh, Pa., in June, and one in Allentown, Pa., in March. As a result of the activities of the subcommittees and of action taken at the March meeting of the committee, certain recommendations affecting standards are submitted in this report.

The Working Committee on Methods of Chemical Analysis (W. C. Hanna, chairman) is conducting cooperative studies on proposed methods of analysis. The Working Committee on Sulfate Resistance (D. G. Miller, chairman) has continued its studies and hopes to present an early recommendation regarding the feasibility of a short-time lean-mortar bar test. Cooperative tests among a large number of laboratories, under the sponsorship of the Working Committee on Fineness (P. H. Bates, chairman), are producing helpful data on different types of fineness tests. The planned work has been continued by the Working Committee on Effects of Alkalies in Portland Cement on the Durability of Concrete (R. F. Blanks, chairman).

Test data relating to Darex AEA as an air-entraining agent in portland cement were reviewed by the Working Committee on Additions (H. J. Gilkey, chairman) at two meetings, and that subcommittee reported favorably to Committee C-1. Later in this report, Committee C-1 recommends revision of the Tentative Specifications for Treated Portland Cement for Concrete Pavements (C 175 – 42 T) to include Darex AEA as an acceptable air-entraining agent. A summary of the data which were considered by the Working Committee, and subsequently presented to Committee C-1, appears in the report of the Working Committee appended hereto.

Some of the changes now proposed by Committee C-1 in the mortar strength tests were recommended by the Working Committee on Strength (O. L. Moore, chairman) subsequent to cooperative tests arranged by that subcommittee.

The Cement Reference Laboratory at the National Bureau of Standards has continued its work, under the supervision of the Subcommittee on Cement Reference Laboratory (G. E. Warren, chairman). The eighth inspection tour among cement laboratories is in progress. The Public Roads Administration again has aided financially and has continued to require Reference Laboratory inspection at laboratories which are to test cement for certain work. Increased attention has been devoted to compression testing machines. The laboratory has cooperated with the different subcommittees of Committee C-1. Committee C-1 has recently referred the Manual on Cement Testing to the laboratory for revision and modernization.

I. New Tentative Standards

The committee recommends that the following three new methods of test be accepted for publication as tentative:

Tentative Method of Test for Determining the Air Content of Portland-Cement Mortar.[1]—This method was submitted by the Sponsoring Committee on Portland Cement (C. E. Wuerpel, chairman) following a cooperative study by members of that subcommittee and certain laboratories which were interested in the deportment of portland cements which contain air-entraining agents. Results of the cooperative tests were distributed to the members of the committee and are presented in Appendix I.

Tentative Method for Determining Vinsol Resin in Cement.[1]—This so-called "methoxyl" method, offered for inclusion in the Tentative Methods of Chemical Analysis of Portland Cement (C 114 – 42 T), was presented to Committee C-1 by the Working Committee on Methods of Chemical Analysis (W. C. Hanna, chairman) in June, 1943, after a cooperative study by six laboratories. It has been modified in certain details since then. The method was developed chiefly by the Hercules Powder Co., the manufacturers of Vinsol resin, and is a modification of the Clark volumetric method.[2] A discussion of the principles of this method will appear in the 1944 edition of the compilation of "A.S.T.M. Standards on Cement."

Tentative Method of Test for Heat of Hydration of Portland Cement.[1]—This method, submitted to Committee C-1 by the Working Committee on Heat of Hydration (G. J. Durant, chairman) is essentially the method contained in the Federal Methods for Sampling, Inspection, and Testing Hydraulic Cements (SS-C-158a) modified by some refinements in calculations and procedure. The results of a study of factors involved in the method, without certain of the refinements of this proposed method, were contained in an A.S.T.M. paper by L. Shartsis and E. S. Newman.[3]

II. REVISION OF TENTATIVE STANDARD

Tentative Specifications for Treated Portland Cement for Concrete Pavements **(C 175 – 42 T)**.—As proposed by the Sponsoring Committee on Portland Cement (C. E. Wuerpel, chairman), the committee recommends that the title of these specifications be changed to read, "Tentative Specifications for Air-Entraining Portland Cement for Concrete Pavements," and that they be revised as appended hereto.[1] In the revised specifications the tensile strength test has been eliminated because of the apparent nonapplicability of the standard methods for determining the amount of mixing water for the mortar. Tentative Method C 109, revised as recommended later in this report, will cover the desired adjustment of mixing water for the compressive strength mortar. Because of the importance of keeping the air content of concrete made with these cements within suitable limits, there has been included a requirement for the amount of air entrained in a 1 to 4 mortar when tested according to the proposed Tentative Method of Test for Determining the Air Content of Portland-Cement Mortar, referred to earlier in this report. A new addition, Darex AEA, is described as acceptable, in Note 4 of Section 3 of the revised specifications.

Before designating Darex AEA as an acceptable addition under these specifications, Committee C-1 reviewed the results of tests conducted at a number of laboratories over some months interval. A summary of that information appears in Appendix I. A chemical method for the determination of the amount of Darex AEA in a cement has been submitted by the makers of Darex. This method, which is now being studied by the Working Committee on Methods of Chemical Analysis, is published as information only, in Appendix II.

---

[1] These methods and specifications were accepted as tentative by the Society and appear in the 1944 Book of A.S.T.M. Standards, Part II.

[2] E. P. Clark, *Journal*, Assn. Official Agricultural Chemists, Vol. 15, p. 136 (1932).

[3] "A Study of the Heat of Solution Procedure for Determining the Heat of Hydration of Portland Cement," *Proceedings*, Am. Soc. Testing Mats., Vol. 43, p. 905 (1943)

III. REVISION OF STANDARDS, IMMEDIATE ADOPTION

Standard Specifications for Portland Cement (**C 150 – 42**).—As proposed by the Sponsoring Committee on Portland Cement (C. E. Wuerpel, chairman), the committee recommends that these specifications be revised as appended hereto.[4] In the revised specifications the compressive strength requirements for types I and III cements have been made the same as those in Federal Specifications for Portland Cement (SS-C-191b) and for High-Early-Strength Portland Cement (SS-C-201a). These changes in strength requirements were considered necessary, because one of the recommended modifications in Method C 109, as given later in this report, requires the mixing water content of the mortar to be adjusted according to the requirements of the individual cements, which is also required by the Federal specifications. Changes have been made in the section on packaging and marking as well as minor changes in other sections, and appropriate revisions to provide proper references to the new separate test methods which are herein recommended.

Standard Methods of Sampling and Physical Testing of Portland Cement (**C 77 – 40**).—The following seven methods of test which are not new in substance but are set up as separate standards, to take the place of the respective methods which heretofore appeared as component parts of Standard Methods C 77, are recommended for immediate adoption as standard as appended hereto:[4]

Standard Methods of:

Sampling Hydraulic Cement,
Test for Fineness of Hydraulic Cement by the No. 200 Sieve,
Test for Normal Consistency of Hydraulic Cement,
Test for Soundness of Hydraulic Cement Over Boiling Water (Pat Test),
Test for Time of Setting of Hydraulic Cement by the Vicat or Gillmore Needles,
Test for Tensile Strength of Hydraulic-Cement Mortars, and
Test for Specific Gravity of Hydraulic Cement.

In effect, this separation, which has been considered as very advisable by Committee C-1, is but a revision of the form of presentation of the test procedures now included in Methods C 77.

Standard Methods of Chemical Analysis of Portland Cement (**C 114 – 42**). These methods have been revised by the Working Committee on Methods of Chemical Analysis (W. C. Hanna, chairman). The important revisions are outlined in Appendix III. In addition proposed changes in form and wording will better present the steps of calculation of results and effect some refinements in details. Nearly all of the changes are of an editorial nature, and no major changes in any of the procedures are involved. Therefore, Committee C-1 recommends the immediate adoption of this revision of Standard Methods C 114.

IV. ADOPTION OF TENTATIVE STANDARDS AS STANDARD

Tentative Methods of Chemical Analysis of Portland Cement (**C 114 – 42 T**).[5] —Sections 1 to 8 of these tentative methods of chemical analysis have now stood for sometime without serious criticism, and it is recommended that they be adopted as standard to be included in Standard Methods C 114, with the addition to Section 7 of a note of caution about variations in temperature of the standard $KMnO_4$ solution.

---

[4] These specifications and methods were accepted as standard by the Society and appear in the 1944 Book of A.S.T.M. Standards, Part II.

[5] 1942 Book of A.S.T.M. Standards, Part II.

Tentative Method of Test for Compressive Strength of Hydraulic-Cement Mortars (**C 109 - 43 T**).—This method has been studied and revised by the Working Committee on Strength (O. L. Moore, chairman). In the proposed, revised method[4] which is recommended for adoption as standard, the requirement for a constant amount of mixing water has been replaced by the provision that the percentage of mixing water will be varied, according to the requirements of the individual cements, so as to secure mortars having a specified consistency as measured by the flow table. A similar requirement for consistency of mortar has been contained in the Federal Specification for Hydraulic Cement (Methods for Sampling, Inspection and Testing) (SS-C-158a) for a long time. Changes have been made in details of compacting the mortar in the cube molds and in the instructions for calculating the strength. Except for revision of the requirement governing the percentage of mixing water, no important changes have been made in the method.

V. EMERGENCY ALTERNATE SPECIFICATION

Emergency Alternate Specifications for Portland Cement (**EA - C 150**).—The C-1 Technical Advisory Committee (J. L. Miner, chairman) to the War Production Board recently secured the opinions and recommendations of its members, and reported accordingly to Committee C-1. It was the opinion of the majority of the subcommittee members that the Emergency Alternate Specifications for Portland Cement (EA - C 150) should be continued in force until the War Production Board's Order L-179 is rescinded, and further that, in any action to rescind Order **L-179** or withdraw **EA - C 150**, provision should be made for the disposal of cement made under these emergency specifications. Committee C-1 considered the details of the subcommittee's report, together with related items including such matters as stocks of cement on hand, conservation of manpower, saving in power and grinding media, and the limitations of the committee's field of activities. As a

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. NEW TENTATIVE STANDARDS			
Test for Determining the Air Content of Portland-Cement Mortar	62	3	3
Test for Determining Vinsol Resin in Cement	62	0	5
Test for Heat of Hydration of Portland Cement	62	0	4
II. REVISION OF TENTATIVE STANDARD			
Spec. for Treated Portland Cement for Concrete Pavements (C 175 - 42 T)[a]	55	8	4
III. REVISION OF STANDARDS, IMMEDIATE ADOPTION			
Spec. for Portland Cement (C 150 - 42)	63	1	2
Sampling and Physical Testing of Portland Cement (C 77 - 40), replaced by the following separate methods:			
Sampling Hydraulic Cement	64	2	2
Test for Fineness of Hydraulic Cement by the No. 200 Sieve	65	1	2
Test for Normal Consistency of Hydraulic Cement	63	2	2
Test for Soundness of Hydraulic Cement Over Boiling Water (Pat Test)	62	2	4
Test for Time of Setting of Hydraulic Cement by the Vicat or Gillmore Needles	65	1	2
Test for Tensile Strength of Hydraulic-Cement Mortars	65	2	1
Test for Specific Gravity of Hydraulic Cements	65	1	2
Chemical Analysis of Portland Cement (C 114 - 42)	65	0	3
IV. ADOPTION OF TENTATIVE STANDARDS AS STANDARD			
Chemical Analysis of Portland Cement (C 114 - 42 T), Sections 1 to 8 only	65	0	3
Test for Compressive Strength of Hydraulic Cement Mortars (C 109 - 43 T), as revised	66	0	2

[a] The classified vote on the revision of the Tentative Specifications for Treated Portland Cement for Concrete Pavements (C 175 - 42 T) was as follows: Affirmative: 29 producers, 18½ consumers, 8 general interests: negative: 3 producers, 1 consumer, 4 general interests.

result of the foregoing considerations, Committee C-1 now recommends to the Society that the Emergency Alternate Specifications for Portland Cement (EA – C 150) be continued until the War Production Board rescinds Order L-179; Committee C-1 further recommends that, when Order L-179 is withdrawn, EA – C 150 be withdrawn by the Society,[6] but that EA – C 150 be published as an Emergency Alternate Specification alone if L-179 is not withdrawn by the War Production Board by the time of publication of the 1944 Book of A.S.T.M. Standards.

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 83 voting members, with the results shown in Table I.

The committee is planning to submit, for publication as tentative specifications, a revision of the Standard Specifications for Masonry Cement (C 91 – 40).[6] This action follows recent considerations by the Sponsoring Committee on Masonry Cement, and is subject to letter ballot of Committee C-1. The Specifications for Masonry Cement (C 91 – 40), are retained unchanged as current standard.

The election of officers for the ensuing term of two years resulted in the re-election of the following:

Chairman, P. H. Bates.
Vice-Chairman, C. F. Conn.
Vice-Chairman, D. Wolochow.
Secretary, G. E. Warren.

This report has been submitted to letter ballot of the committee which consists of 83 voting members; 71 members returned their ballots, of whom 68 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the committee,

P. H. BATES,
Chairman.

G. E. WARREN,
Secretary.

---

[6] See Editorial Note, below.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee C-1 presented to the Society through Committee E-10 on Standards the following recommendations:

Revised Tentative Specifications for:

Masonry Cement (C 91 – 44 T), for publication as a tentative revision of Standard Specifications C 91 – 40, and

Withdrawal of Emergency Alternate Specifications for:

Portland Cement (EA – C 150).

The first recommendation was accepted by the Standards Committee on August 28, 1944, and the tentative specifications appear in the 1944 Book of A.S.T.M. Standards, Part II. The second recommendation was accepted by Committee E-10 on December 11, 1944.

REPORT OF WORKING COMMITTEE ON ADDITIONS

Under date of October 27, 1943, application was made by the Dewey & Almy Chemical Co. for the consideration of the Darex Air-Entraining Agent as an acceptable addition under the Tentative Specifications for Treated Portland Cement for Concrete Pavements (A.S.T.M. Designation: C 175). Darex AEA was described by the manufacturers as a triethanolamine salt of a sulfonated hydrocarbon.

The Dewey & Almy Chemical Co. submitted data covering the performance of Darex, which data were developed in the following laboratories during the past two years:[1]

Massachusetts Institute of Technology,
Massachusetts State Highway Department,
Kansas State College,
University of California,
Bureau of Reclamation,
Iowa State College,
Wisconsin State Highway Department,
Pennsylvania-Dixie Cement Corp.,
Marquette Cement Manufacturing Co.,
Warner Laboratories (H. J. Knopel),
Municipal Laboratories of St. Paul,
Certified Concrete Company of St. Paul, and
Dewey & Almy Chemical Co.,

A condensed version of the results of a majority of the tests above mentioned was distributed to the members of Committee C-1 under date of February 14, 1944.[2]

The following test data were reviewed:

1. All physical and chemical tests required by the specifications,
2. Compression tests on concretes, maximum sizes of aggregates from $\frac{3}{8}$ to $2\frac{1}{2}$ in. Specimens tested: 3 by 6-in. to 6 by 12-in. cylinders,
3. Modulus of rupture on 6 by 6 by 30-in. beams, $1\frac{1}{2}$ in. maximum size aggregate,
4. Vertically and horizontally cast bond specimens,
5. Freezing-and-thawing tests of concrete in both calcium chloride and water,
6. Air voids determinations, and
7. Volume change of concrete in both air and water storage.

Concrete mixing procedures were:

1. 2-sack paver mixer—2 min.
2. $\frac{1}{2}$-sack batch mixer—3 min.
3. Hand mix—3 min.
4. 3-yd. horizontal transit drum type —10 and 30 min.
5. 3-yd. high-discharge transit mixer—10 and 30 min.
6. Lancaster mixer—3 min.

As a result of individual study and of its group consideration of these data at two meetings, the Working Committee on Additions recommends that Darex AEA be accepted by Committee C-1, in accordance with the formal request of the Dewey & Almy Chemical Co., as an air-entraining agent under A.S.T.M. Specifications C 175 in amount not exceeding 0.05 per cent by weight of the cement.

This report was adopted by an affirmative vote of five of the seven voting members of this Working Committee, two of the members not voting. (Mr. C. C. Ahles was unable to attend either meeting. Mr. D. G. Runner proxied for Mr. F. H. Jackson at the second meeting. Mr. Kennedy, of the Dewey & Almy Chemical Co., refrained from voting because of his connection with that company.)

---

[1] The laboratories are not listed in the same order in which their work is discussed in the attached summary of data.

[2] A summary and discussion of the data prepared by the chairman of the Working Committee appears in the Appendix on p. 300.

A Proposed Method of Chemical Analysis for Darex AEA in Portland Cement, submitted by the Dewey & Almy Chemical Co., is published as information in Appendix II.

Respectfully submitted on behalf of the subcommittee,

H. J. GILKEY,
Chairman.

APPENDIX

THE DATA ON DAREX AEA

NOTE.—Herein the word Darex refers to Darex AEA (Darex Air-Entraining Agent).

As summarized by H. J. Gilkey, chairman, Working Committee on Additions.

FOREWORD

Because of the number of laboratories which have contributed data on Darex, the considerable range of tests and mixtures covered, and the further fact that most of the tests are not within the fully-standardized category, the different sets of data are not readily comparable one with another. Generally speaking, each phase of each investigation requires individual scrutiny and no general comparative summary or tabulation is feasible. The essential aspect of each test series, regardless of where it was conducted, is the fully controlled comparison between the Darex treated cement and the "blank" (the same cement and the same mixture without Darex).

The primary function of the air-entraining agent is to increase the resistance to freezing and thawing in the presence of either water or chloride salts, such as those used in snow removal, even though such added resistance may entail some loss in strength. Pertinent tests naturally include, therefore, such properties as freezing and thawing, strength at various ages, workability effects, bond with steel, and possible swelling and shrinkage under wetting and drying out. The uniformity of results secured with different representative cements is also an important item. Since the durability seems to be definitely related to the increased air voids produced by the addition, measurements of air voids secured under different conditions of mixing and for different mixtures are important as are also indications relative to the degree of uniformity to be expected. Since a majority of the tests were made on small specimens and small maximum size of aggregate, there needed to be some tests on job-size aggregates and specimens and on field-type mixtures to make sure that there is no important reversal of indications for the changed conditions. It seemed desirable, also, to check on how concrete made from Darex cement compares in essential properties with concrete made from cement having other additions which have been considered acceptable (notably Vinsol resin), not with the idea of attempting to demonstrate a commercial advantage but rather as a check upon whether or not the Darex cement could be expected to perform in a manner comparable to the performance of other treated cements which have been passed upon as acceptable.

A few test data are supplied on comparative results from standard acceptance tests but these are not considered essential to the committee in formulating its recommendation since a Darex cement must pass the same acceptance tests as an untreated cement and any significant deficiency here would result in routine rejection regardless of a Committee C-1 pronouncement of acceptability as an addition.

The statements which follow represent the attempt of the chairman of the Working Committee on Additions to supply impartial generalizations on what the several sets of data show. They are subject to all the potential errors and inaccuracies of human appraisal which may arise from misplaced emphasis and inequitable ratings of different factors and facts. The actual data, rather than this attempted summary of findings, are recommended as the one proper source for careful study. For example, no attempt is made here to supply adequate descriptions of mixtures, aggregates, methods of test, or any of the other several factors essential for a well-rounded picture of a project. It does need to be repeated, however, that all such factors were nominally identical for the blank and the Darex mixtures, unless definitely indicated as otherwise in the summary.

Presumably, the chairman of Committee C-1, or any member thereof, or the Dewey & Almy Chemical Co. can provide access to the data in condensed form as supplied to the entire membership of Committee C-1.

SUMMARY OF INVESTIGATIONS

Laboratory A

A type II cement blank and the same cement with 0.035 per cent Darex added were compared for normal consistency, initial set, final set, and compressive strength at 3, 7, and 28 days. The results for the blank and the Darex cements were virtually identical. The Darex gave no adverse indication for any of these properties, the 28-day strength being slightly higher for the Darex-treated cement (4300 psi. against 4100 psi.).

Comparative shrinkage tests on 2 by 2 by 10 in. 1:3 mortar bars, moist cured for 16 days followed by dry storage at 70 F. and 50 per cent relative humidity, showed no discernible differences in shrinkage between the blank and Darex specimens at ages of 28, 90, and 180 days.

A type I laboratory-ground clinker was used for comparing freezing-and-thawing performances (in water) of concretes made from the blank, 0.035 per cent Darex, and 0.03 per cent Vinsol resin cements, respectively. Corresponding percentages of air voids were 2, 2.8, and 5.1 per cent, respectively, with initial strengths of 5490, 5220, and 4530 psi. At 90 cycles expansions were 0.28, 0.02, and 0.02 per cent. At 100 cycles the blank failed and at 230 cycles the Darex and the Vinsol resin concretes had expanded 0.05 and 0.04 per cent with percentage weight losses of 6 and 8 (the loss for the blank having been 25 per cent at 100 cycles just prior to failure).

Laboratory B

For grind No. 1 portland cement, ground with 0.03 per cent Darex and without, the relative weights of 5.5 sack mixtures at equal water-cement ratios and slumps were 152.0 and 156.1 lb. per cu. ft., respectively, for Darex and the blank. Strengths for the Darex cement were slightly higher at 1 and 3 days and slightly lower at 7 and 28 days (4930 against 5330 psi. at the latter age).

Under comparative freezing-and-thawing tests in water, the relative expansions were 115 and 500 at 96 cycles and 345 and 7550 at 456 cycles. The blank disintegrated completely at 468 cycles. The loss in weight for the Darex concrete was slightly under 1 per cent at 600 cycles.

Laboratory C (first listing)

Comparative strength tests on nominal 5.8 sack, equal slump and equal water-cement-ratio mixtures using brand No. 2 cement, comparing the blank cement with 0.03 per cent Darex and Vinsol resin cements gave highest strengths for the Darex concrete at ages of 1, 3, 7, and 28 days. For blank, Darex, and Vinsol resin concretes the strengths at 3 months were 5740, 5440, and 4410 psi. and at 2 yr. were 5680, 5530, and 4500 psi. The corresponding air voids were 0.2, 1.5, and 3.0 per cent.

Identical tests with brand No. 3 cement and the same order of additions as above gave indications of the same order, the 3-month and 2-yr. strengths being 5900, 5680, and 5060 psi. and 6820, 6600, and 5900 psi., respectively, with air voids of 0.5, 1.9, and 2.2 per cent.

Freezing-and-thawing tests in calcium chloride solution showed losses in dynamic modulus of 59.0, 30, and 32.4 per cent for the No. 3 cement at 15 cycles and of 70.8, 23.5, and 22.4 per cent for the No. 2 cement at 30 cycles, when using the additions in the same order as above.

Similar strength and freezing-and-thawing tests of nominal 6.3 sack mixtures of brands Nos. 3, 4, and 5 cements gave results of the same order as those cited for the blank, Darex, and Vinsol resin concretes.

Laboratory D

Three rather widely different brands of cement (laboratory ground), Nos. 6, 7 and 8, were compared in 5.5 and 7.5 sack mixtures in the blank and with 0.03 per cent Darex. For compressive strengths, compared at 1, 7, 28 days and 6 months, the Darex led by a substantial margin in nearly every case for the 5.5 sack mix, but for the 7.5 sack mixture Darex was slightly below the blank at 6 months for cements Nos. 7 and 8, and decidedly lower in strength for cement No. 6 (6385 and 4360 psi. at 28 days and 8400 and 5710 psi. at 6 months). Weights were decreased 4 or 5 lb. per cu. ft. (2.8 to 3.4 per cent added air voids).

For freezing-and-thawing tests in calcium chloride, specimens with Vinsol resin were included. The blanks all disintegrated at about 20 cycles but the Darex and Vinsol-resin concretes showed little length change, little loss in dynamic modulus or weight change after 130 cycles. The leaner mixtures (5.5 sacks) were affected more than the 7.5 sack concretes.

For the same three cements and similar mixtures, comparisons of freezing-and-thawing tests were made using water instead of calcium chloride. For the 5.5 sack mixtures the blanks all disintegrated at 35 or 40 cycles, but for the 7.5 sack mixture disintegration of the blanks occurred between 110 and 130 cycles. At 130 cycles weight losses were not great for either the Darex or the Vinsol resin mixtures.

Under 28- and 84-day immersions in water at 70 F. the expansion of the Darex concrete was about the same as that for the blanks for the same three brands of cement. In like manner, for 28- and 84-day dry air storage at 120 F. the shrinkages of blank and Darex concretes were about the same for both the 5.5 and 7.5 sack mixtures. In other words, for normal soaking and drying out the presence or absence of Darex seemed not to be significant.

Laboratory E

Comparisons of 14-day compressive and bond strengths (both horizontally and vertically cast), with and without Darex, were made for 5.5 and 7.5 sack mixtures from the same lots of Nos. 6, 7 and 8 brands of cement ground at laboratory D and used in its tests. For nearly every mixture the compressive strength of the Darex concrete exceeded that of the blank, usually by a substantial margin. The bond stresses developed by the Darex concretes also averaged somewhat above those for the blanks with some individual interchanges in relative positions. The horizontally cast bond specimens were tested as push-outs and the vertically cast as pull-outs.

Laboratory F

Drying-out shrinkage measurements comparing blank mortars with Darex mortars for Nos. 6, 7 and 8 cements ground at laboratory D, were made on 1.5 by 1.5 by 6-in. mortar bars at periods of 21 and 28 days and 2 and 3 months drying. In nearly all cases the shrinkage was slightly greater for the Darex but in no case was there any marked difference in the amount of shrinkage. At 3 months the extreme range was 0.0094 to 0.0121 per cent for the blank concrete and from 0.0107 to 0.0141 per cent for the Darex concrete.

Laboratory G

Data secured from brand No. 9 cement blank and with Darex interground at the plant gave comparative chemical analyses and compound compositions which were virtually identical for the blank and the Darex cements. The standard physical tests for normal consistency, setting time, soundness (5 hr. in steam) and fineness (specific surface and No. 325 sieve) also agreed closely. Tensile strengths of 1:3 standard mortars were nearly identical, being slightly higher for the Darex concrete at all ages. Compressive strengths of 1:2.75 plastic mortars were slightly higher for the Darex concrete at 1 and 7 days and for the blank concrete at 3 and 28 days.

Comparisons of 6-sack concretes at nominally equal water contents gave about 2 in. greater slump for the 0.03 per cent Darex and equal or slightly higher compressive strengths at 1, 3, 7, and 28 days. Mixtures with a slightly lower water-cement ratio for the Darex concrete (5.5 against 6 gal. per sack) to produce equal slumps gave somewhat higher compressive strengths for the Darex at all four test ages. The air voids were about 5.3 per cent for the Darex against 2.6 per cent for the blank.

Some supplementary physical tests comparing blanks with 0.025 and 0.04 per cent Darex grab samples (at identical mill charges for blank and Darex) gave the same results for normal consistency, time of set and soundness. The Darex cement was somewhat finer by both the surface area and No. 325 sieve criteria. The differences in 1:3 standard tensile strengths at 1, 3, 7, and 28 days were slight, the Darex cement averaging a trifle higher than the blank. In like manner, the 1:2.75 plastic mortar compressive strengths were somewhat higher for the Darex, except for the 28-day 0.04 per cent Darex which was 4108 against 4158 psi. for the blank. The corresponding 0.025 Darex concrete gave 4458 psi., however.

Laboratory H

Tests were made on typical highway concretes (6 by 12-in. cylinders, aggregates up to 2.5 in., and fineness modulus for mixed aggregates within the range of 5.76 to 6.37). Brand No. 9 cement, with and without 0.03 per cent Darex, ground at laboratory G plant, was used in mixtures which ranged from 5.17 to 6.37 sacks per cubic yard with a nominal slump of 2 in. Air voids were about 1 and 4 per cent, respectively, for blank and Darex concretes. At 3, 7 and 28 days the strengths of the Darex concretes averaged about 95, 95.5, and 89 per cent as strong as the blanks.

Laboratory C (second listing)

Using the same cements as those in the laboratory H tests above, laboratory C made tests of concrete in 4 by 8-in. specimens using 1-in. maximum aggregate (fineness modulus 5.5 to 5.7) in mixtures from 4.4 to 6.6 sacks per cubic yard tested at 3, 7, and 28 days. Air voids were from 0.50 to 0.90 per cent for the blanks and from 3.40 to 5.80 per cent for the Darex concretes. Mixtures were at nominally equal slumps of 2 in. with net water-cement ratios slightly higher for the blank than for the Darex (of the order 0.710 *versus* 0.625; 0.575 *versus* 0.512; 0.550 *versus* 0.483; and 0.482 *versus* 0.443). In nearly every instance the Darex concretes were somewhat stronger than the blanks. For the richest mixtures the difference was the more pronounced. Laboratory C duplicated the laboratory G series with the brand No. 10 cement discussed below, the results being quantitatively similar and qualitatively identical with those secured from the laboratory G series.

Laboratory J

Physical tests of blank and 0.03 per cent Darex (cement ground and tested by the company) show the blank to be slightly finer, and to have slightly lower normal consistency, 30 min. shorter initial set, 1 hr. shorter final set, and identical autoclave expansions at 0.17. Both tensile and compressive mortar strengths were virtually identical at 1, 3, and 7 days. Chemical analyses and compound compositions were also virtually identical for the blank and Darex cement.

Laboratory K

Brands Nos. 9 and 10 cements (blank and 0.03 per cent Darex) as described heretofore, were used for 7 and 28 day compressive strength tests on 6 by 12-in. cylinders and for 7 day flexural strength tests on 6 by 6 by 30-in. beams. Mixing time was 3 min. in a batch mixer. Mixtures were nominal 5.5 sacks per cubic yard and slump 1 in. for cement No. 9 and 2.5 in. for cement No. 10, the water-cement ratio being 0.06 lower for the Darex in each case. Air voids were 0.4 and 0.1 per cent for blank concretes and 3.8 and 4.6 per cent for the Darex concretes. Compressive strengths were slightly higher for the Darex concretes at both 7 and 28 days and the 7-day moduli of rupture were virtually identical for the two.

Laboratories L and M

Brand No. 10 cement (as heretofore described) was used for these tests in which the participants included (besides the above), laboratories N and C. Using 1½-in. maximum aggregate in 11 pairs of mixtures (blank and 0.03 per cent Darex) ranging from 4 to 6 sacks per cubic yard, 7-day compressive strengths were secured for all tests and 7-day moduli of rupture were observed at laboratory N. Variables included type of mixer (horizontal transit for batches 1 to 9, and high discharge transit for batches 10 and 11; also batch mixer in laboratory K tests previously discussed); mixing time (10 and 30 min., 2 min. for the batch mixer); and rate of drum rotation (5 rpm. for all but mix 5 at 10 rpm. and the batch mixer at 18 rpm.).

The Darex concretes gave higher strengths in most cases and a higher overall average. Increasing the length of mixing time had no consistent effect on air voids in the blank and seemed to decrease slightly rather than increase the voids in the Darex. Mixing time had no marked effect on strengths. Doubling the rate of rotation (5 to 10 rpm. in the horizontal transit mixer) had no marked effect on air voids or strength. There is no evidence that the high discharge or batch type mixer produced results essentially different from those secured in the horizontal transit type. These tests appear to indicate that variable air entrainment for variable time of mixing or mixer equipment should not prove to be a seriously disturbing factor in the case of Darex cement.

APPENDIX I

REPORT ON COOPERATIVE STUDIES OF PROPOSED METHOD OF TEST FOR AIR CONTENT OF PORTLAND-CEMENT MORTAR

The Tentative Method of Test for Air Content of Portland-Cement Mortar[1] which is recommended for acceptance by the Society was developed in the course of a cooperative investigation by four cement companies[2] and the Central Concrete Laboratory, Corps of Engineers, U. S. Army. The purpose of the investigation was to develop means by which the air-

TABLE I.—AIR CONTENTS AND WATER-CEMENT RATIO OF STANDARD MORTAR CONTAINING PLAIN AND VINSOL RESIN-TREATED CEMENTS AS DETERMINED BY CENTRAL CONCRETE LABORATORY.

Cement Serial No.	Vinsol Resin Content, per cent	Water-Cement Ratio[b]	Air Content of Mortar, per cent										
			Round 1			Round 2			Round 3			Average of all Tests	Average Deviation
			A	B	C	A	B	C	A	B	C		
PLAIN CEMENTS													
5[a]	0.001	80.5	3.5	4.1	4.1	5.1	4.4	4.9	...	...	...	4.4	0.4
1	0.002	80.0	4.0	4.0	4.7	3.8	...	...	...	...	...	4.1	0.3
2	0.002	78.2	4.5	4.7	3.9	4.5	4.0	4.7	5.5	...	...	4.5	0.4
4	0.001	77.7	4.8	5.7	5.6	4.8	5.6	5.3	...	...	...	5.3	0.4
3	0.001	79.8	4.0	4.3	4.9	5.1	5.8	5.1	4.9	6.6	...	5.1	0.6
CEMENTS WITH NEUTRALIZED VINSOL RESIN													
13	0.005	70.9	10.7	10.7	10.5	10.2	10.8	10.6	10.5	11.1	11.9	10.8	0.3
33	0.006	70.0	9.6	9.5	9.6	...	...	...	...	...	...	9.6	0.03
34	0.007	68.0	11.7	11.4	11.7	...	...	...	...	...	...	11.6	0.1
14	0.009	70.0	11.6	11.2	11.2	12.6	12.3	12.0	12.0	11.9	...	11.9	0.3
40	0.012	58.0	19.7	18.5	19.8	...	...	...	...	...	...	19.3	0.6
15	0.013	59.1	18.0	18.7	18.7	18.7	18.3	18.2	19.0	...	...	18.5	0.3
35	0.013	63.0	15.1	14.8	14.8	...	...	...	...	...	...	14.9	0.1
36	0.016	56.0	20.1	19.9	20.5	...	...	...	...	...	...	20.2	0.2
17[a]	0.018	59.1	20.2	20.1	20.6	19.1	19.4	19.8	20.1	20.4	20.6	20.0	0.4
16	0.019	55.5	20.8	21.2	21.2	20.8	21.0	20.3	21.5	21.0	20.5	20.9	0.3
18	0.022	58.5	19.8	19.9	19.7	19.9	19.7	19.6	20.2	20.2	...	19.9	0.2
19	0.032	57.9	20.6	20.5	20.1	20.3	20.1	20.0	20.1	20.7	20.0	20.3	0.2
22[a]	0.034	55.7	24.3	24.0	24.6	24.9	24.8	23.8	23.8	24.2	23.6	24.2	0.4
20[a]	0.035	66.3	15.0	15.3	15.3	14.2	15.2	14.2	15.4	15.0	...	15.0	0.3
21	0.042	53.6	24.2	24.7	24.7	24.5	24.0	23.9	24.7	25.8	24.7	24.6	0.4
CEMENTS WITH FLAKE VINSOL RESIN													
12	0.012	62.0	17.6	17.7	17.5	17.1	17.3	17.3	17.8	17.4	17.5	17.5	0.2
8	0.024	57.9	19.2	19.7	19.3	20.0	20.2	20.0	20.6	20.3	20.4	20.0	0.4
6	0.025	65.5	15.2	13.6	15.6	15.0	14.6	14.7	15.1	15.5	14.4	14.9	0.5
7	0.026	66.9	13.8	13.7	13.8	14.2	14.3	14.4	14.4	14.4	14.9	14.2	0.3
11	0.028	55.8	23.0	23.1	23.0	23.7	24.0	23.9	23.6	23.6	23.8	23.5	0.3
9	0.042	64.7	15.1	15.0	15.0	14.7	14.8	14.6	15.0	14.5	15.4	14.9	0.2
10[a]	0.042	65.5	15.7	15.8	15.5	15.9	15.4	15.7	15.9	16.3	15.8	15.8	0.2

[a] Type I cement; all others are Type II as prescribed in the Standard Specifications for Portland Cement (A.S.T.M. Designation: C 150), 1942 Book of A.S.T.M. Standards, Part II, p. 1.

[b] Percentage of water by weight of cement.

---

[1] This method was accepted as tentative by the Society and appears in the 1944 Book of A.S.T.M. Standards, Part II, p. 1227.

[2] Universal Atlas Cement Co.
Lone Star Cement Corp.
Pennsylvania-Dixie Cement Corp.
Glens Falls Portland Cement Co.

entrainment characteristics of cement meeting the A.S.T.M. Tentative Specifications for Treated Portland Cement for Concrete Pavements (C 175 – 42 T) could be made regulable. As the investigation proceeded, it became evident that regulation of air entrainment could not be achieved satisfactorily by the simple expedient of specifying the amount of the air-entraining agent to be interground with the cement. A rapid physical test of the air-entraining characteristic of the cement was necessary.

TABLE II.—AIR CONTENTS AND WATER-CEMENT RATIO OF STANDARD MORTAR CONTAINING PLAIN AND VINSOL RESIN-TREATED CEMENTS AS DETERMINED BY FIVE COOPERATING LABORATORIES.

Cement Serial No.	Vinsol Resin Content, per cent	Air Content of Mortar, per cent							Water by Weight of Cement, per cent						
		Lab. A[b]	Lab. B[b]	Lab. C[b]	Lab. D[c]	Lab. E[d]	Grand Average	Average Deviation	Lab A[b]	Lab. B[b]	Lab. C[b]	Lab. D[c]	Lab. E[d]	Grand Average	Average Deviation
PLAIN CEMENTS															
5[a]	0.001	4.4	3.4	2.3	3.3	4.0	3.5	0.6	80.5	80.9	78.8	80.9	80.0	80.2	0.5
1	0.002	4.1	4.0	2.4	3.5	3.6	3.5	0.5	80.0	80.0	80.0	80.0	80.9	80.2	0.3
2	0.002	4.5	4.2	2.9	4.4	3.6	3.9	0.5	78.2	78.2	78.2	78.2	80.9	78.7	0.8
4	0.001	5.3	5.1	4.4	5.5	5.1	5.1	0.3	77.7	77.3	75.4	77.3	76.4	76.8	0.7
3	0.001	5.1	4.7	6.4	4.2	6.6	5.4	0.9	79.8	80.9	73.0	81.8	76.4	78.4	2.9
CEMENTS WITH NEUTRALIZED VINSOL RESIN															
13	0.005	10.8	10.4	9.7	10.7	11.1	10.5	0.4	70.9	70.9	70.9	70.9	70.9	70.9	0.0
33	0.006	9.6	12.0	11.5	...	...	11.0	1.0	70.0	64.0	66.7	...	...	66.9	2.1
34	0.007	11.6	13.2	12.7	...	...	12.5	0.6	68.0	64.0	68.0	...	...	66.7	1.8
14	0.009	11.9	11.6	10.9	11.9	13.8	12.0	0.7	70.0	70.0	71.5	71.8	67.3	70.1	1.2
40	0.012	19.3	18.5	20.5	...	...	19.4	0.7	58.0	59.3	56.0	...	...	57.8	1.2
15	0.013	18.5	17.3	18.5	18.5	21.7	18.9	1.1	59.1	59.1	59.1	60.0	53.7	58.2	1.8
35	0.013	14.9	15.8	16.6	...	...	15.8	0.6	63.0	61.0	61.0	...	...	61.7	0.9
36	0.016	20.2	19.1	20.8	...	...	20.0	0.6	56.0	59.3	56.0	...	...	57.1	1.5
17[a]	0.018	20.0	19.7	20.0	20.9	21.6	20.4	0.6	59.1	59.1	59.7	59.1	57.7	58.9	0.5
16	0.019	20.9	20.2	21.2	20.5	21.1	20.8	0.3	55.5	56.4	57.3	57.3	54.6	56.2	0.9
18	0.022	19.9	20.8	20.8	20.2	21.3	20.6	0.4	58.5	57.3	58.2	58.2	55.5	57.5	0.9
19	0.032	20.3	21.3	20.4	19.6	22.4	20.8	0.8	57.9	57.3	59.1	57.3	55.5	57.4	0.9
22[a]	0.034	24.2	23.7	24.5	23.7	25.5	24.3	0.5	55.7	56.4	56.4	56.4	54.1	55.8	0.7
20[a]	0.035	15.0	15.0	14.2	15.5	17.5	15.4	0.8	66.3	66.4	68.2	67.3	63.6	66.4	1.1
21	0.042	24.6	25.2	25.2	25.8	25.3	25.2	0.3	53.6	53.6	53.6	53.6	49.1	52.7	1.4
CEMENTS WITH FLAKE VINSOL RESIN															
12	0.012	17.5	16.9	17.3	17.5	19.8	17.8	0.8	62.0	61.8	61.8	62.7	57.3	61.1	1.5
8	0.024	20.0	19.6	19.5	19.2	21.9	20.0	0.7	57.9	59.1	59.1	59.1	55.5	58.1	1.2
6	0.025	14.9	15.5	15.7	14.8	17.6	15.7	0.8	65.5	65.5	63.3	65.5	62.7	64.5	1.2
7	0.026	14.2	13.6	13.4	14.2	16.8	14.4	0.9	66.9	68.2	68.2	69.1	63.6	67.2	1.6
11	0.028	23.5	23.5	23.5	22.1	25.0	23.5	0.6	55.8	57.3	56.4	57.3	51.8	55.7	1.6
9	0.042	14.9	15.4	14.4	15.5	17.7	15.6	0.9	64.7	64.5	65.1	64.5	59.1	63.6	1.8
10[a]	0.042	15.8	15.5	14.9	15.3	17.4	15.8	0.7	65.5	65.5	67.3	65.5	62.7	65.3	1.0

[a] Type I cement; all others are type II as prescribed in the Standard Specifications for Portland Cement (A.S.T.M. Designation: C 150 – 42), 1942 Book of A.S.T.M. Standards, Part II, p. 1.
[b] Average values for three rounds.
[c] Average values for one round.
[d] Average values for two rounds.

The investigation entailed the actual manufacture on a commercial scale of several thousand barrels of cement from single clinker burns at each of five mills. The procedure followed was to grind untreated cement for about 1 hr. and extract a 10-bbl. sample; start adding flake (unneutralized) Vinsol resin and adjust to 0.03 per cent, then grind for about 1 hr. and extract a 10-bbl. sample; cease adding flake Vinsol resin and start adding neutralized[3] Vinsol resin and adjust to about 0.01 per cent, then grind for about 1 hr. and extract a 15-bbl. sample; and finally, increase the addition of the sodium-resinate to about 0.03 per cent Vinsol resin, then grind for about 1 hr. and extract a 15-bbl. sample. The samples were packed in export-type bags and forwarded to the Central Concrete Laboratory. Upon arrival at the laboratory, the contents of a majority of the individual bags were analyzed and enough of the nominal 0.01 and 0.03 neutralized-Vinsol resin cements were machine blended to provide an adequate quantity of 0.02 neutralized-Vinsol resin cement for the desired tests. This procedure provided a total of 20 samples, that is, five cements treated in four different ways.

---

[3] An aqueous solution of sodium hydroxide and Vinsol resin (15 NaOH to 100 Vinsol resin, by weight).

TABLE III.—COMPARISON OF AIR CONTENT OF MORTARS AND OF CONCRETE.

Cement Serial Number	Vinsol Resin Content, per cent	Water-Cement Ratio of Mortar[b]	Air in Mortar, per cent	Air in Concrete, per cent		Ratio of Air Contents of Mortar and Concrete	
				Gravel	Stone	Gravel	Stone
RC-97	plain	80.0	4.1	1.3	2.5	3.1	1.5
RC-99	0.009 NVR[c]	67.2	12.1	3.6	5.1	3.4	2.4
RC-117	0.017 NVR	55.5	19.9	6.4	8.0	3.1	2.5
RC-98	0.030 VR[d]	63.5	15.1	4.3	6.3	3.5	2.4
RC-101	plain	78.0	4.4	2.0	2.1	2.2	2.1
RC-103	0.009 NVR	70.0	11.2	4.0	4.8	2.8	2.3
RC-118	0.019 NVR	61.8	17.0	5.6	7.3	3.0	2.3
RC-102	0.029 VR	66.3	13.0	5.1	4.7	2.6	2.8
RC-105	plain	79.0	5.0	2.6	4.1	1.9	1.2
RC-107	0.008 NVR	62.0	15.5	4.7	5.7	3.3	2.7
RC-119	0.013 NVR	57.3	19.7	6.5	9.0	3.0	2.2
RC-106	0.028 VR	57.3	23.8	10.0	14.1	2.3	1.7
RC-109	plain	77.3	5.8	1.5	2.7	3.9	2.1
RC-111	0.010 NVR	66.4	14.3	4.9	4.9	2.9	2.9
RC-120	0.020 NVR	55.5	22.4	7.5	9.8	3.0	2.3
RC-110	0.028 VR	65.5	13.4	4.3	4.8	3.1	2.8
RC-113[a]	plain	78.2	5.1	2.0	2.8	2.5	1.8
RC-115[a]	0.012 NVR	64.5	15.5	4.9	6.4	3.2	2.4
RC-121[a]	0.020 NVR	58.2	21.1	7.0	9.6	3.0	2.2
RC-114[a]	0.030 VR	67.3	14.3	5.5	6.3	2.6	2.3
Average						3.0	2.3
Grand Average						2.65	

[a] Type I cement; all others are type II, as designated in the Standard Specifications for Portland Cement (A.S.T.M. Designation: C 150), 1942 Book of A.S.T.M. Standards, Part II, p. 1.

[b] Percentage of water by weight of cement.

[c] NVR indicates cements with neutralized Vinsol resin.

[d] VR indicates cements with flake Vinsol resin.

In addition to the 20 samples described above, 2 samples of commercial cements (type I and type II cement as prescribed in A.S.T.M. Standard Specifications for Portland Cement (C 150 – 42)) which had been used on field projects were included in the air-content study.

Samples of the 22 cements were prepared carefully and divided into five parts for distribution to the cooperating laboratories where the method of test for determining air content in mortar[4] was used to determine the air-entraining characteristics of the various untreated, flake-Vinsol resin-treated and neutralized-Vinsol resin-treated cements. Each laboratory was requested to run 3 groups of 3 tests each on different days. The individual data obtained by the Central Concrete Laboratory are given in Table I. The average data obtained by each laboratory and the grand average and average deviations are given in Table II. Both of these tables include data on

---

[4] Similar to the subject test method in all respects except that a 1000-ml. measure was used instead of the 500-ml. measure.

TABLE IV.—TESTS FOR COMPARING AIR CONTENT OF MORTARS MEASURED IN 1000-ML. AND 500-ML. MEASURES.

Cement Serial Number	1000-ml. Measure		500-ml. Measure		Difference in Air Content, per cent
	Burmister Flow, in.	Air Content, per cent	Burmister Flow, in.	Air Content, per cent	
RC-97	2.4	7.0	2.5	6.1	
	2.4	7.0	2.6	6.3	
	2.5	6.9	2.4	6.3	
Average	2.4	7.0	2.5	6.2	−0.8
RC-113	2.8	4.6	2.5	5.2	
	2.9	4.6	2.6	5.4	
	2.7	4.6	2.8	5.2	
Average	2.8	4.6	2.6	5.3	+0.7
RC-101	2.9	3.1	2.9	4.2	
	2.9	3.5	2.6	4.6	
	2.8	3.5	2.7	4.6	
Average	2.9	3.4	2.7	4.5	+1.1
RC-102	2.7	11.9	2.4	12.6	
	2.8	12.1	2.5	12.9	
	2.8	12.1	2.4	12.0	
Average	2.8	12.0	2.4	12.5	+0.5
RC-106	2.9	17.5	2.7	18.3	
	2.8	17.7	2.7	17.9	
	2.8	18.0	2.9	18.2	
Average	2.8	17.7	2.8	18.1	+0.4
RC-110	2.4	17.1	2.6	15.8	
	2.7	16.9	2.6	15.8	
	2.4	16.7	2.6	16.1	
Average	2.5	16.9	2.6	15.9	−1.0
RC-114	2.4	17.2	2.4	17.3	
	2.4	16.5	2.4	17.3	
	2.4	16.5	2.5	17.4	
Average	2.4	16.7	2.4	17.3	+0.6
RC-99	2.5	10.7	2.9	11.3	
	2.6	10.8	2.6	12.1	
	2.8	10.6	2.4	12.0	
Average	2.6	10.7	2.6	11.8	+1.1
RC-103	2.5	12.0	2.6	11.8	
	2.5	12.0	2.7	11.4	
	2.5	12.0	2.5	12.1	
Average	2.5	12.0	2.6	11.8	−0.2
RC-108	2.9	18.6	2.5	19.4	
	2.8	18.4	2.4	19.6	
	2.8	18.8	2.4	19.4	
Average	2.8	18.6	2.4	19.5	+0.9
RC-100	2.9	20.0	2.8	20.4	
	2.8	20.1	2.9	20.4	
	2.8	20.1	2.9	20.5	
Average	2.8	20.1	2.9	20.4	+0.3
RC-115	2.4	17.0	2.4	16.9	
	2.4	16.7	2.4	17.6	
	2.5	16.6	2.5	17.2	
	2.4	16.8	2.4	17.2	+0.4
RC-104	2.4	20.6	2.6	20.9	
	2.6	20.2	2.9	20.5	
	2.7	20.2	2.8	20.7	
Average	2.6	20.3	2.8	20.7	+0.4
RC-116	2.9	24.8	2.4	24.6	
	2.8	24.3	2.7	24.7	
	2.8	24.4	2.6	24.6	
Average	2.8	24.5	2.6	24.6	+0.1
RC-112	2.8	24.0	2.5	24.0	
	2.8	24.0	2.7	24.5	
	2.7	24.1	2.7	24.2	
Average	2.8	24.0	2.6	24.2	+0.2

27 cements, because 5 additional cements were added to the list after the first results were obtained and these were tested by three of the laboratories.

The data in Tables I and II show a definite relationship of air content with amount of neutralized Vinsol resin despite the presence of cements from 5 different mills. The data show, also, the definite absence of a relationship of air content with amount of flake Vinsol resin in the cements.

The data in Tables I and II show, also, the excellent concordance of the test method within the laboratory and between laboratories. In view of the fact that this was the first experience of the laboratories with the method, it might be expected that the concordance will improve with use and experience.

The data in Table III, which shows the relationship of the air content in mortar with that in concrete, were obtained by determining the air content of concrete containing each of two types of coarse aggregate made with each of the cements included in the test program. The air content of the concrete was determined by the weight per cubic foot method given in the latest proposed revision of the Standard Method of Test for Yield of Concrete (C 138 – 39).[5]

In view of the fact that extensive field experience and laboratory tests have shown that an air content in concrete of 5 to 6 per cent is the optimum for obtaining maximum workability, bleeding reduction, and durability, with a minimum of strength reduction, the tests reported herein show that the ratio of air-in-mortar to air-in-concrete is about 2.65. It thus appears logical to establish a limit of 14 ± 4 per cent for the air content in the Cement Specifications C 175.

Subsequent to the completion of the investigation reported above, it became evident that a reduction in quantity of standard sand required by the test would be most desirable. In order to determine the practicability of reducing the size of the test batch, a series of experiments were conducted by the Central Concrete Laboratory on 15 cements in which the air contents were determined in parallel with a 500-ml. measure and a 1000-ml. measure. The results of this investigation, given in Table IV, indicate that the air content may be determined with either size measure with approximately equal accuracy. Therefore, the method was revised to require the smaller and more economical size of batch.

Respectfully submitted on behalf of the Sponsoring Committee on Portland Cement,

C. E. WUERPEL,
Chairman

---

[5] 1944 Book of A.S.T.M. Standards, Part II, p. 487.

APPENDIX II

PROPOSED METHOD OF CHEMICAL ANALYSIS FOR DAREX AIR-ENTRAINING AGENT IN PORTLAND CEMENT[1,2]

This is a proposed method and is published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 260 S. Broad St., Philadelphia 2, Pa.

1. *Apparatus: (a) Distillation Apparatus.*—Use an all-glass apparatus consisting of a 500-ml. Erlenmeyer flask and a Friedrichs spiral condenser in which the condensed distillate comes out at the lower end.

(*b*) *Colorimeter.*—Use a photoelectric colorimeter fitted with a selective light filter to give transmission limits of approximately 400 and 450 mμ. A spectrophotometer, which makes it possible to use a narrow band anywhere within the range of vision, may be used and the center of the band used in this method should be 425 mμ.

2. *Reagents:* (*a*) *Water.*—Use distilled ammonia-free water throughout.

Note 1.—Ammonia-free water may be obtained by redistilling ordinary distilled water to which 0.1 g. of Na_2CO_3 and 0.1 g. of $KMnO_4$ per liter have been added. Reject the first quarter and the last sixth of the distillate. The center portion is substantially ammonia-free.

(*b*) *Standard Ammonium Chloride Solution (1 ml. = 0.00025 g. Darex AEA).*—Prepare a stock solution which contains 3.93 g. of NH_4Cl per liter. Dilute 10 ml. of this stock solution to 1 liter to make the standard solution.

Note 2.—The standard solution contains 0.0000103 g. of nitrogen per ml. and is equivalent to 0.00025 g. of Darex AEA. The standard solution is unstable and should not be kept for more than two days, but the stock solution may be kept for a period of at least six months.

(*c*) *Alkaline Solution of Potassium Permanganate.*—Dissolve 20 g. of $KMnO_4$ and dilute to 1 liter. Dissolve 70 g. of NaOH (or 100 g. of KOH) and dilute to 1 liter. Mix the two solutions.

(*d*) *Nessler Reagent.*—Dissolve 50 g. of KI in about 35 ml. of water and add a saturated solution of $HgCl_2$ until a slight precipitate persists. Dissolve 144 g. of NaOH (or 202 g. of KOH) and add to the solution of $2HgI_2 \cdot 2KI$. Dilute the combined solution to 1 liter and allow it to clarify by sedimentation. Use the clear solution in the procedure.

Note 3.—The reagent should give the characteristic yellow-brown color with ammonia within 5 min. and should not produce a precipitate with small amounts of ammonia within 2 hr.

3. *Calibration of Colorimeter.*—Calibrate the colorimeter with the standard solution of NH_4Cl. Omit the distillation described in Section 4. Mix the standard solution and Nessler reagent in the colorimeter tube or cell. Set the zero of the instrument with distilled water and Nessler reagent in the colorimeter tube or cell.

Note.—The details of the calibration depend on the instrument and should be carried out as instructed by the manufacturer. The measure-

---

[1] This proposed method is under the jurisdiction of the A.S.T.M. Committee C-1 on Cement. Published as information, June, 1944.

[2] This proposed method is based on a procedure recommended by the American Public Health Association and the American Water Works Association for determining albuminoid nitrogen in water and described in "Standard Methods for the Examination of Water and Sewage," Eighth Edition, p. 45 (1936). The general outline of the method was proposed by the Dewey & Almy Chemical Co., manufacturers of Darex Air-Entraining Agent, to Committee C-1 on Cement, and this procedure is published as information only, pending study by the Working Committee on Methods of Chemical Analysis, of Committee C-1. Darex AEA is a triethanolamine salt of a sulfonated hydrocarbon. TDA, or any other substance that yields ammonia on treatment with alkaline permanganate, will interfere with the determination.

The working Committee on Methods of Chemical Analysis is conducting a cooperative investigation of this method which is expected to result in an improved description.

ment of light passing through a colored solution should be made between 10 and 25 min. after the addition of Nessler reagent. The full intensity of the color is attained in about 10 min., but the solution may become turbid if it is allowed to stand more than 25 min. If the reagent produces no color with distilled water, the use of the reagent may be omitted in the setting of the zero.

4. *Procedure.*—(*a*) Put 100 ml. of water in the Erlenmeyer flask and attach the Friedrichs spiral condenser. Distill off 50 ml. of the water and discard the distillate. Disconnect the condenser, add 25 ml. of the alkaline solution of $KMnO_4$ and 75 ml. of water, and immediately replace the condenser. Distill 48 to 49 ml. of the water into a 50-ml. volumetric flask (Note 1). Add 1 ml. of the Nessler reagent to the distillate, dilute to the 50-ml. mark, mix, and allow to stand 10 min. (Note 2). Transfer the solution to a colorimeter tube or cell, place it in the colorimeter, and set the instrument at zero.

NOTE 1.—A colorimeter tube may be used to receive the distillate directly if a volume of 50 ml. can be correctly measured in the tube.

NOTE 2.—If no color is produced, the distillation and treatment with the Nessler reagent may be omitted and distilled water may be used directly. Otherwise the zero should be set as directed, because when so set the colorimeter gives readings automatically corrected for a blank.

(*b*) Place 5 g. of cement (Note 3) and 100 ml. of water in the 500-ml. distilling flask and proceed with distillation as described in Paragraph (*a*). When the condenser is disconnected after the preliminary part of the distillation, make certain that all of the cement is still in suspension. If any cement is sticking to the flask, loosen it with a glass rod and wash the rod before the addition of the alkaline solution of $KMnO_4$ and more water. Treat the distillate with the Nessler reagent and place in the colorimeter as described in Paragraph (*a*). Measure the intensity of the light passing through the solution as directed by the manufacturer of the colorimeter.

NOTE 3.—If the color produced by 5 g. of cement is too dark to be measured precisely, the colored solution may be diluted or a smaller sample may be used.

(*c*) *Calculation.*—From the measurement of the transmitted light, calculate the content of Darex AEA in the sample to the nearest 0.001 per cent.

Alternate Method

NOTE.—In case of dispute, results obtained in accordance with Section 4 shall govern.

5. *Apparatus:* (*a*) *Distillation Apparatus.*—Use the apparatus described in Section 1 (*a*).

(*b*) *Colorimeter.*—Any equipment that can be used for comparing colored solutions visually may be used. A colorimeter of the Duboscq immersion type is suitable if a good degree of precision is desired. In the absence of a colorimeter of any kind, a number of matched Nessler color comparison tubes of 50-ml. capacity may be used.

6. *Reagents.*—Use the ammonia-free water and the reagents described in Section 2.

7. *Procedure.*—(*a*) Proceed with the distillation and add the Nessler reagent to the distillate as described in Section 4. If a visual colorimeter is available, complete the determination and calculate the percentage of Darex AEA in the manner appropriate to the instrument. If a colorimeter is not available, put the colored solution in a Nessler tube and compare it with several tubes which contain solutions of known concentrations. In some cases it may be more convenient to omit the volumetric flask and receive the distillate directly in a Nessler tube.

(*b*) *Calculation.*—Calculate the content of Darex AEA in the sample to the nearest 0.001 per cent.

APPENDIX III

SUMMARY OF PROPOSED REVISIONS IN METHODS OF CHEMICAL ANALYSIS OF PORTLAND CEMENT

(C 114 - 42 and C 114 - 42 T)[1]

The following summary presents the more important features of the proposed revision in the A.S.T.M. Methods of Chemical Analysis of Portland Cement (C 114 - 42 and C 114 - 42 T).

No attempt is made here to present in detail the numerous minor editorial changes which do not affect the substance of the methods, but consist mainly of items such as rearrangement of sections and paragraphs, changes in terminology to conform to current practice, revisions in section numbers, rewording for clarity and for desirable uniformity. Section numbers of the present methods are used in outlining the following notes.

The new material, which comprises new Sections 4 to 6, is presented in full. Section 4 differs somewhat from the corresponding Section 3 of the Tentative Recommended Practices for Apparatus and Reagents for Chemical Analysis of Metals (E 50 - 43 T), after which it is modeled, as the American Chemical Society does not have specifications for all reagents mentioned in Methods C 114. References to published specifications and test methods are added.

One of the principal changes involves a rearrangement of the methods separating the routine from the alternate procedures. In the revised methods the routine procedures will be described first and these will be followed by the alternate methods which are provided for those who wish to use procedures that are shorter or more convenient than the routine determinations for certain components. The revised methods will require, however, that in case of dispute, results obtained by the routine methods shall govern.

At the end of each procedure there will be included a section on calculations which will include a formula to use together with any necessary explanation. This is an important addition to the methods and should be of assistance to the analyst.

CHANGES IN METHODS C 114 - 42

New Sections.—Add new Sections 4 to 6 to read as follows, renumbering the subsequent sections accordingly:

4. *Purity of Water and Reagents:* (*a*) *Water.*—References to water shall be understood to mean distilled water.

(*b*) *Reagents.*—Unless otherwise indicated, it is intended that all reagents shall conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, when such specifications are available.[2] When such specifications are not available, the best grade available should be used. Other grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

5. *Concentration of Reagents.*—(*a*) *Concentrated Acids and Ammonium Hydroxide.*—When acids and ammonium hydroxide are specified by name or chemical formula only, it shall be under-

---

[1] For an explanation of this recommendation see p. 296.

[2] "A.C.S. Analytical Reagents," American Chemical Society, Washington, D. C., March, 1941. For suggestions on the testing of reagents not listed by the American Chemical Society, see "Reagent Chemicals and Standards," by Joseph Rosin, D. Van Nostrand Co., Inc., New York, N. Y. (1937).

stood that concentrated reagents of the following specific gravities or concentrations are intended:

Hydrochloric acid, HCl	sp. gr. 1.18
Hydrofluoric acid, HF	48 per cent
Nitric acid, HNO_3	sp. gr. 1.42
Sulfuric acid, H_2SO_4	sp. gr. 1.84
Ammonium hydroxide, NH_4OH	sp. gr. 0.90

The desired specific gravities or concentrations of all other concentrated acids shall be stated whenever they are specified.

(*b*) *Diluted Acids and Ammonium Hydroxide.*—Concentrations of diluted acids and ammonium hydroxide, except when standardized, shall be specified as a ratio stating the number of volumes of the concentrated acid or ammonium hydroxide to be diluted with a given number of volumes of water, as in the following example: HCl (1:99) means 1 volume of concentrated HCl (sp. gr. 1.18) diluted with 99 volumes of water.

(*c*) *Standard Solutions*—Concentrations of standard solutions shall be expressed as normalities or as equivalents in grams per milliliter of the component to be determined, for example: 0.1 *N* $Na_2S_2O_3$, or $K_2Cr_2O_7$ (1 ml. = 0.004 g. Fe_2O_3).

(*d*) *Nonstandardized Solutions.*—Concentrations of nonstandardized solutions prepared by dissolving a solid reagent in a solvent shall be specified in grams of the reagent per liter of solution, and it shall be understood that water is the solvent unless otherwise specified, for example: NaOH (200 g. per l.) means 200 g. of NaOH dissolved in water and diluted with water to 1 liter. In the case of certain reagents the concentration may be specified as a percentage by weight, for example ethanol (50 per cent) means a solution containing 50 g. of ethanol per 100 g. of solution. Other nonstandardized solutions may be specified by name only and the concentration of such solutions will be governed by the instructions for their preparation.

6. *Glassware.*[3]—(*a*) All glass apparatus and vessels used in analytical work should be carefully selected to meet the particular requirements for each operation. Standard volumetric flasks, burettes, and pipettes should be of precision grade.

(*b*) New and improved types of glass apparatus are available, including colored glass for the protection of solutions affected by light, alkali-resistant glass for use where superior resistance to alkalies is important, and a high-silica glass having exceptional resistance to thermal shock. Standard-taper, interchangeable, ground-glass joints are useful in analytical work.

Section 4.—In the second line of the note under Section 4 insert "all" after "not."

Section 5.—Omit Section 5, this section having become awkward due to the increasing number of procedures. For certain procedures, special directions are necessary for a blank. Therefore, in the proposed revision of Methods C 114 a paragraph covering the blank determination is to be added to each procedure in which it is required. This is in accordance with the arrangement used in the A.S.T.M. methods for chemical analysis of metals. The proposed wording of the paragraph on blanks in Methods C 114 in most cases is as follows: "Make a blank determination, following the same procedure and using the same amounts of reagents, and correct the results obtained in the analysis accordingly."

Section 6(a).—Delete "finely powdered" in the first sentence.

Section 9.—Change the first sentence of Paragraph (*a*) to read "Dissolve 10 g. of $SnCl_2 \cdot 2H_2O$ in 25 ml. of HCl and 75 ml. of water." Change the italic heading of Paragraph (*d*) to read "Standard Potassium Dichromate Solution (1 ml. = 0.004 g. Fe_2O_3)." At the end of Paragraph (*d*) add a new sentence to read "Calculate the Fe_2O_3 equivalent of the solution in grams per milliliter by multiplying the weight of iron in the amount of iron wire used by 1.430 (molecular ratio of Fe_2O_3 to 2Fe) and dividing by the volume of $K_2Cr_2O_7$ solution required."

---

[3] For further information the following references may be consulted:

E. F. Mueller and R. M. Wilhelm, "Methods of Testing Thermometers," *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part I, p. 493 (1938);

J. J. Moran, "Methods of Testing Volumetric Glassware," *Proceedings*, Am. Soc. Testing Mats., Vol. 41, p. 492 (1941);

J. P. Bader and E. L. Peffer, "Methods of Testing Hydrometers," *Proceedings*, Am. Soc. Testing Mats., Vol. 42, p. 463 (1942)

E. L. Peffer and G. C. Mulligan, "Testing of Glass Volumetric Apparatus," Nat. Bureau Standards *Circular C434*, Superintendent of Documents, Government Printing Office, Washington, D. C. (1941).

Section 10.—Delete the words "having a titer not greater than 0.004 g. of Fe_2O_3 per ml." from the next to the last sentence.

Section 11.—In the revised procedure for calcium oxide the elimination of manganese now prescribed when manganic oxide is determined will be made mandatory in all cases.

Section 14.—Change the italic heading of Paragraph (*c*) to read "Standard Sodium Hydroxide Solution (0.33 N)." Delete the fourth sentence of Paragraph (*c*) and the second sentence of Paragraph (*d*).

Section 15.—In the third sentence of Note 2, after "$KMnO_4$" add "as MnO_2."

Section 17(*b*).—In the next to the last sentence, change "solution of $(NH_4)_2C_2O_4 \cdot H_2O$ (4 per cent)" to read "ammonium oxalate solution (50 g. per l.)."

Section 20.—In Paragraph (*a*), change "100 ml. of water" to read "water and dilute to 100 ml." Change first two lines of Paragraph (*b*) to read "Gladding Wash Solution.—Dissolve 100 g. of NH_4Cl in water, dilute to 500 ml., and add."

Section 24.—Delete Note 2.

Section 25.—Change the italic heading of Paragraph (*b*) to read "Standard Sodium Hydroxide Solution (0.3 N)."

Section 27.—In the first sentence, change "0.9008" to read "0.90."

Section 29.—In the first sentence, change "5.63" to read "5.64."

New Section.—Under "Chloroform-Soluble Organic Substances" add a new section to read as follows:

> *Reagents: Chloroform:*—If the blank determination exceeds 0.0015 g., the chloroform should be distilled before use. Chloroform recovered in the procedure may be slightly acid but can be reused for the portions to be shaken with the aqueous acid solution of the sample in the 1-liter funnel. Chloroform used for washing the filter and transferring the extract should be fresh or distilled from fresh chloroform.

Section 32.—At the end of Paragraph (*a*), change "separate" to read "stand 15 min. to separate." After the first sentence of Paragraph (*b*) insert a new sentence to read "Keep the amount of the aqueous layer transferred to an absolute minimum, since excessive water in the 125-ml. funnel may result in incomplete extraction of the scum and may cause an emulsion which does not separate readily." Change the fourth sentence of Paragraph (*b*) to read "Shake the 250-ml. funnel," deleting the remainder of the present sentence. Change the fourth and fifth sentences of Paragraph (*d*) to read "Evaporate the extract at a low temperature (not over 63 C.) to dryness (Note 5) and heat it in an oven at 57 to 63 C. for 3 min. Pass dry air into the vessel for 15 sec., cool, and weigh." Change the third, fourth, and fifth sentences of Note 5 to read "When a quick evaporation is desired, the solution may be evaporated on a hot plate at a low heat under a stream of dry air through a glass tube (about 1 cm. in inside diameter) until the solution is about 0.3 cm. in depth. Then remove the vessel from the hot plate and continue a slow stream of dry air until the residue appears dry. Then continue with a more rapid stream of dry air for 5 min. at room temperature before placing the vessel in the oven at 57 to 63 C. After each 3-min. heating period in the oven, pass dry air into the vessel for about 15 sec. before weighing." In footnote 10, delete the first and third sentences.

Section 34.—In Paragraph (*a*) under "Separate Determinations" insert "Free Calcium Oxide" just above "Water-Soluble Alkali." Delete Paragraph (*b*). In the proposed revision of Methods C 114, the number of decimal places to be used in reporting results is covered by a paragraph on calculations in each procedure.

CHANGES IN METHODS C 114 - 42 T

Sections 1 to 8 of Tentative Methods C 114 - 42 T are to be incorporated in the revised Standard Methods C 114, with the following changes:

Section 6.—In the first sentence, change "5.636" to read "5.64." In the fifth sentence, change "0.005636" to "0.0056357."

Section 7.—Add the following two notes:

NOTE 1.—The temperature of the standard $KMnO_4$ solution should not vary from its standardization temperature so much as to cause a serious error in the determination of CaO. At ordinary room temperatures the volume of pure water changes to the extent of 0.01 to 0.04 per cent for each degree Centigrade.

NOTE 2.—When the amount of calcium oxalate is very small, its oxidation by $KMnO_4$ is slow to start. Before the titration, add a little $MnSO_4$ to the solution to catalyze the reaction.

Section 8.—Designate this procedure as Method A. Add the following note:

NOTE.—Alternate Method A may be used when it is desired to determine MgO in the filtrate from the determination of CaO (Section 7). Alternate Method B or C[4] may be used when the determinations of SiO_2, Al_2O_3, and CaO are omitted.

---

[4] Alternate Methods B and C are the methods now described in Sections 15 and 17 of Standard Methods C 114 - 42.

REPORT OF COMMITTEE C-7

ON

LIME

Committee C-7 on Lime held one meeting during the year, on June 30, 1943, in Pittsburgh, Pa.

The year has seen the death of two of the members of Committee C-7: Bernard L. McNulty, one of the representatives of the Marblehead Lime Co., and J. F. O'Reilly, representing the Operative Plasterers' and Cement Finishers' International Assn. of the United States and Canada. The total membership at present is 54; of whom 25 are classified as producers, 6 as consumers, and 23 as general interest members.

NEW TENTATIVE STANDARD

The committee recommends new Tentative Definitions of Terms Relating to Lime[1] to include definitions of the following: run-of-kiln quicklime, quicklime sizes, hydraulic hydrated lime, high-calcium hydraulic hydrated lime, and high-magnesium hydraulic hydrated lime.

REVISION OF STANDARD, IMMEDIATE ADOPTION

The committee recommends for immediate adoption revisions in the Standard Specifications for Hydrated Lime for Structural Purposes (C 6 – 31) which changes will eliminate references to Mason's hydrate and will confine these specifications to normal hydrated lime for finishing, the revised specifications to be issued under the title "Specifications for Normal Finishing Hydrated Lime."[2]

ADOPTION OF TENTATIVE STANDARD AS STANDARD

The committee recommends that the Tentative Definitions of Terms Relating to Lime (C 51 – 41 T) be approved for reference to letter ballot of the Society for adoption as standard.

ADOPTION OF TENTATIVE REVISION AS STANDARD

On the recommendation of its Subcommittee V on Methods of Test for Lime and Lime Products, Committee C-7 recommends that the tentative revision[3] of the Standard Methods of Chemical Analysis of Limestone, Quicklime, and Hydrated Lime (C 25 – 29), issued in 1942, to insure complete hydration of the lime, be revised as follows and approved for reference to the Society for adoption as standard:

Section 27 (b).—Change the first three sentences from their present form: namely,

> Weigh 0.5 g. of the prepared sample (Section 2) (passing a No. 100 (149-micron) sieve) and brush carefully into a 350-ml. Erlenmeyer flask containing 10 to 20 ml. of distilled water (Note 1), and immediately stopper the flask with a rubber stopper. Disperse the sample thoroughly in the water by giving the flask a slight swirling motion and allow to stand for 5 min. Remove the stopper, add 15 g. of granulated

---

[1] These definitions were accepted as tentative by the Society and appear in the 1944 Book of A.S.T.M. Standards, Part II, p. 1243.

[2] These revised specifications were accepted as standard by the Society and appear in the 1944 book of A.S.T.M. Standards, Part II, p. 85.

[3] 1943 Supplement to Book of A.S.T.M. Standards, Part II, p. 157.

> sugar (sucrose), and then add 150 ml. of distilled water at room temperature on top of the sugar (Note 2).

to read as follows:

> Weigh 0.5 g. of the prepared sample (Section 2) (passing a No. 100 (149-micron) sieve) and brush carefully into a 350-ml. Erlenmeyer flask containing about 20 ml. of distilled water (Note 1), and immediately stopper the flask loosely with a rubber stopper. Disperse the sample thoroughly in the water by a swirling motion, heat to boiling, and boil for 2 min. Remove the stopper, add 150 ml. of distilled water at room temperature, and then add 15 g. of granulated sugar (sucrose) (Note 2).

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 54 members, with the results shown in Table I.

TABLE I.—ANALYSIS OF LETTER BALLOT.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. NEW TENTATIVE STANDARD			
Def. of Terms Relating to Lime	26½	0	5½
II. REVISION OF STANDARD, IMMEDIATE ADOPTION			
Spec. for Hydrated Lime for Structural Purposes (C 6 - 31)	26½	2	3½
III. ADOPTION OF TENTATIVE STANDARD AS STANDARD			
Def. of Terms Relating to Lime (C 51 - 41 T)	28½	0	3½
IV. ADOPTION AS STANDARD OF TENTATIVE REVISION OF STANDARD			
Methods of Chemical Analysis of Limestone, Quicklime, and Hydrated Lime (C 25 - 29)	17	1	10

Committee C-7 recommends that all other standards and tentative standards under its jurisdiction be continued in their present status without revision.

Several new specifications are under consideration.

ACTIVITIES OF SUBCOMMITTEES

Advisory Committee (W. C. Voss, chairman) held a meeting during the Pittsburgh meeting at which time the program for the year was planned and a special working committees organized to prepare tests on the extrusion machine, the autoclave, and workability and sand-carrying capacity of masonry mortars.

A revised procedure for subcommittee work has been drafted and presented to the committee for action.

Subcommittee II on Structural Lime (H. R. Staley, chairman) has under consideration revised specifications for masonry and finish limes.

Subcommittee III on Lime for Chemical Industries (R. W. McAllister, chairman) has held no meetings during the past year but has been actively engaged in considering Master Specifications for Quicklimes and Hydrated Limes for the Chemical Industry. Such master specifications are now ready for submission to the general committee after having been twice submitted to the subcommittee members. In the specifications an attempt has been made to devote one section to describe the general requirements of lime for miscellaneous chemical purposes and to list in a "special requirements" section the particular requirements which lime should meet for special uses.

Subcommittee V on Methods of Test for Lime and Lime Products (J. F. Carle, chairman) has approved by letter ballot vote the proposed revision of the rapid sugar method as given earlier in this report. Work is being done on the settling rate test and heat of hydration test. Consideration is being given to data on availability of lime by different methods submitted by one of its members.

Subcommittee IX on Research Problems (C. J. Koehler, chairman) conducted a questionnaire survey of its members regarding a suitable test for the soundness of lime, following which work was undertaken upon the autoclave test by a special working committee. Seven laboratories cooperated and the report of this work has been submitted to the committee with recommendations for future work.

Five laboratories cooperated in tests on a small model of the extrusion machine and the report with its recommendations was circulated to the committee.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, W. C. Voss.
Vice-Chairman, J. A. Murray.
Vice-Chairman, J. F. Carle.
Secretary, L. K. Herndon.

This report has been submitted to letter ballot of the committee which consists of 54 members; 28 members returned their ballots, of whom 25 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the committee,

W. C. Voss,
Chairman.

L. K. HERNDON,
Secretary.

REPORT OF SPECIAL SUBCOMMITTEE ON USE OF THE AUTOCLAVE FOR TESTING LIME

In this analysis of the autoclave test data submitted by seven different laboratories, an attempt has been made to list the conditions of the particular tests, to summarize the results obtained, and to make whatever general conclusions that may seem to be justified from a study of the data as a whole. No attempt will be made to include all of the voluminous data collected, but typical data have been selected and are included in the form of graphs and tabulations.

SUMMARY OF INVESTIGATIONS

Laboratory No. 1

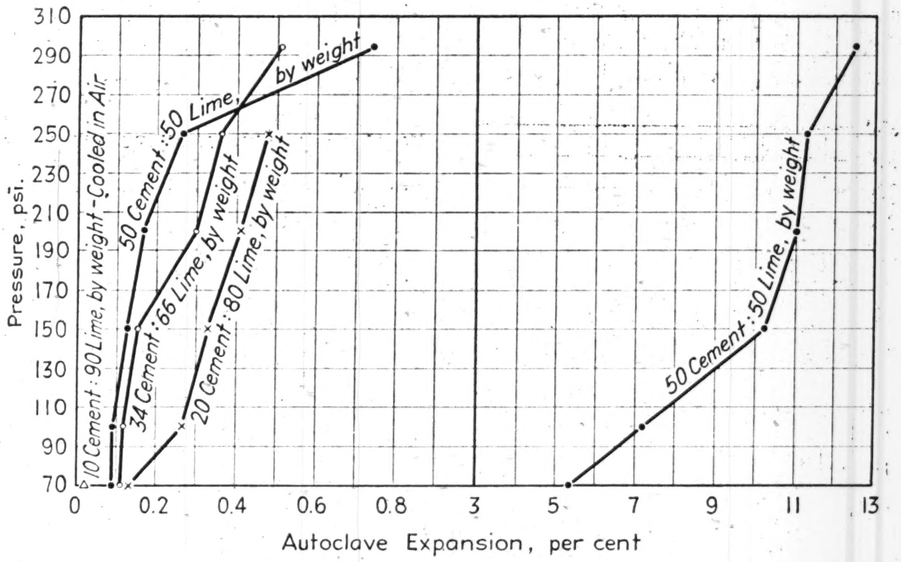
Laboratory No. 1 submitted data from an extensive series of tests of both neat and sanded mixes of lime and cement. The limes used comprised three regular dolomitic hydrated limes and three pressure hydrated limes produced by the same manufacturers. The pressure hydrated limes were not analyzed for determination of unhydrated oxide content, although it is known from plant control tests that they contained less than 8 per cent of unhydrated oxides. One brand of portland cement (having an expansion of 0.284 per cent) was used in all tests. Five ratios of cement to lime were used, ranging from 0:1 to 1:1 by weight. Three parts by weight of graded Ottawa sand were used in the sanded mixes. The test specimens were 1 by 1 by 5-in. bars. These were cured as specified in the A.S.T.M. Standard Method of Test for Autoclave Expansion of Portland Cement (C 151 - 43).[1] Six autoclave conditions were used: 70 psi. and 100 psi. for 4 hr.; 150 psi. and 200 psi. for $3\frac{1}{2}$ hr.; 250 psi. and 295 psi. for 3 hr. Two types of cooling of the autoclaved specimens were used: namely, in water as specified in Method C 151, and also in a constant temperature room (70 F. and 50 per cent relative humidity).

Results:

1. Neat mixes showed progressively increasing expansion with increase of pressure (Fig. 1). Autoclaving for 3 hr. at 295 psi. gave consistently and appreciably greater expansions than autoclaving for 4 hr. at 100 psi. Sanded specimens, however, tended to show less expansion at 250 and 295 psi. for 3 hr. than at 200 psi. for $3\frac{1}{2}$ hr. (Fig. 2).
2. The difficulty of obtaining perfect specimens and complete test data increased with decreasing cement-lime ratios in the mixes. For example, only a few tests were obtained on 10:90 mixes, and these were obtained with pressure hydrated dolomitic limes and at low autoclave pressures.
3. In some cases, increasing the proportions of lime to cement resulted in decreased expansions.
4. In general, sanded specimens showed less expansion than the corresponding neat specimens with pressure hydrated dolomitic limes, but in a few instances with regular dolomitic hydrates, the expansions of sanded specimens were greater than the expansion of neat specimens.
5. The three regular dolomitic hydrates gave expansions of approximately

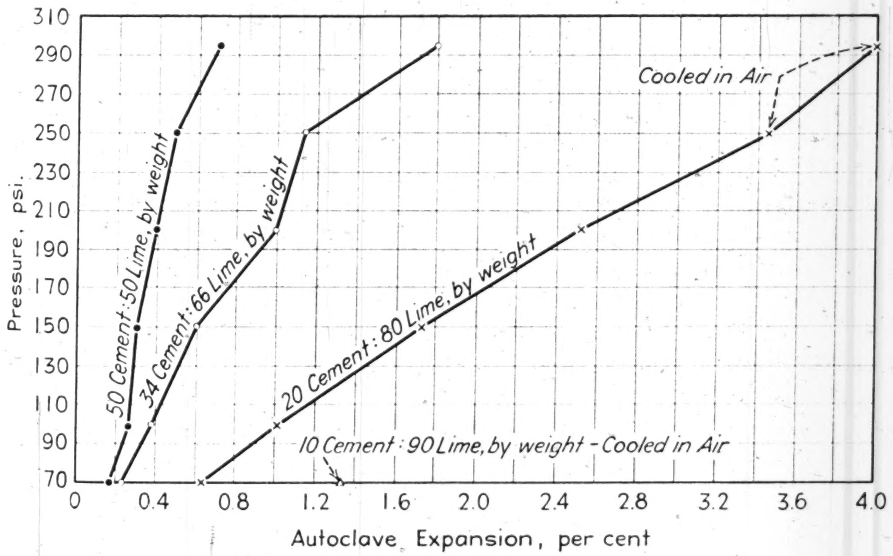
---

[1] 1944 Book of A.S.T.M. Standards, Part II.



Lime No. 49—Pressure hydrated dolomitic lime, neat paste, water cooling except where designated otherwise, 5-in. gage length.

Lime No. 57—Regular dolomitic hydrate, neat paste, water cooling, 5-in. gage length.



Lime No. 56—Pressure hydrated dolomitic lime, neat paste, water cooling except where designated otherwise, 5-in. gage length.

FIG. 1.—Relation of Autoclave Expansion to Pressure for Neat Cement-Lime Mixes—Laboratory No. 1.

the same order. Expansion values for the three pressure hydrates differed widely, as illustrated by the comparative values of 0.56 per cent and 4.02 per cent for corresponding mixes from two of the limes.

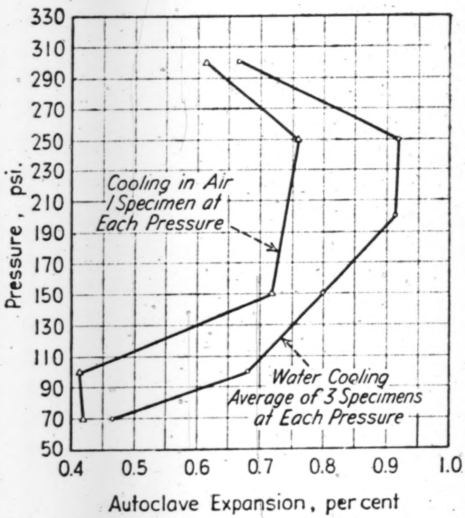


FIG. 2.—Relation of Autoclave Expansion to Pressure for Cement-Lime-Sand Mixes—Laboratory No. 1.

Lime No. 56—Pressure hydrated dolomitic lime, 1 part of 20:80 cement-lime mixture to 3 parts of graded Ottawa sand 5-in. gage length.

6. A large proportion of the autoclaved specimens disintegrated when cooled in water. This difficulty was largely obviated by cooling the specimens in air.

Laboratory No. 2

The greater portion of the data submitted by Laboratory No. 2 covered the control tests on daily production of pressure hydrate over a period of months. Some tests also were made on regular dolomitic hydrate and on competitive pressure hydrates.

TABLE I.—RELATION OF AUTOCLAVE EXPANSION TO PERCENTAGE OF UNHYDRATED OXIDES—LABORATORY NO. 2.

Unhydrated Oxides, per cent	Autoclave Expansion, per cent	Unhydrated Oxides, per cent	Autoclave Expansion, per cent
0.5	1.566	5.4	1.492
1.0	2.500	5.5	6.875
1.3	2.500	5.9	3.437
1.6	1.058	6.2	1.314
2.0	2.500	6.7	1.455
2.3	2.712	7.0	3.750
2.6	1.137	7.4	2.560
2.7	2.500	7.7	5.000
2.8	1.626	8.1	5.312
2.8	1.672	8.5	2.812
2.9	1.602	8.5	2.813
2.9	1.875	8.9	3.125
3.1	2.175	9.0	5.000
3.2	2.500	9.1	6.250
3.2	6.344	9.5	4.378
3.4	3.125	9.5	4.378
3.5	1.925	9.6	3.750
3.8	1.411	9.7	4.378
3.8	1.875	10.3	4.378
3.9	1.093	10.4	5.625
4.0	1.494	11.4	3.126
4.0	6.421	11.7	5.000
4.4	0.836	12.0	5.650
4.4	1.133	12.0	6.250
4.8	3.777	12.2	3.126
5.0	3.190	12.7	5.625
5.0	4.375	14.0	5.312
5.2	1.249		

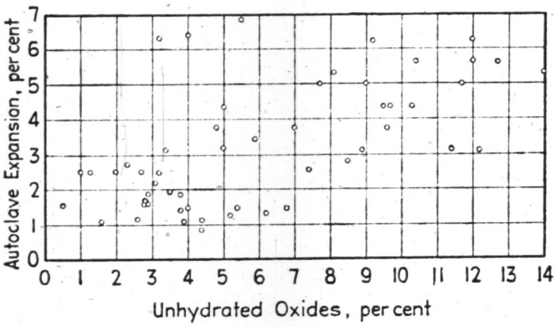


FIG. 3.—Relation of Autoclave Expansion to Percentage of Unhydrated Oxides—Laboratory No. 2

Plant laboratory tests on pressure hydrated dolomitic lime, made over 6-month period, using procedure prescribed in A.S.T.M. Method C 151 – 43. Mix proportions equal 1 part of cement to 1 part of hydrated lime.

Both neat and sanded 1:1 cement-lime mixes were autoclaved. Test specimens were 1 by 1 by 10-in. bars and the procedure prescribed in A.S.T.M. Method C 151 was followed in autoclaving.

In other tests, specimens of sanded mixtures were autoclaved after curing in a damp closet for periods up to 6 months.

Results:

1. The expansion figures for samples of daily production varied over a wide range and showed no rational relation to the unhydrated oxide content of the lime (Table I, Fig. 3). This indicates that some property other than unhydrated oxide content is predominant in determining expansion characteristics. These data are also indicative of the wide variation that is possible with many different samples. Most of the other data presented are representative of more ideal conditions regulated for the control of variables.

TABLE II.—CHEMICAL ANALYSES OF LIMES USED —LABORATORY NO. 3.

	Dolomitic Masons' Pressure Hydrate	Regular Dolomitic Finish	High Calcium Masons' Hydrate + Overburned Material	Dolomitic Masons' Pressure Hydrate + 12.5 per cent Overburned Material
Acid insoluble matter, per cent	0.14	0.10	0.24	0.16
R_2O_3, per cent	0.26	0.30	0.72	0.16
CaO, per cent	43.67	47.70	73.57	43.41
MgO, per cent	28.95	33.08	0.75	28.96
SO_3, per cent	1.28	1.51	0.33	1.92
CO_2, per cent	2.02	1.88	1.47	1.61
Moisture at 105 C., per cent	0.28	0.55	0.58	0.31
Loss on ignition, per cent	25.50	17.67	24.49	25.68

Reconstruction of the Above Chemical Analyses as Calculated Compounds
(Federal Specification SS-L-351a)

	Dolomitic Masons' Pressure Hydrate	Regular Dolomitic Finish	High Calcium Masons' Hydrate + Overburned Material	Dolomitic Masons' Pressure Hydrate + 12.5 per cent Overburned Material
Moisture at 105 C., per cent	0.28	0.55	0.58	0.31
Acid insoluble matter, per cent	0.14	0.10	0.24	0.16
R_2O_3, per cent	0.26	0.30	0.72	0.16
$CaCO_3$, per cent	4.57	4.29	3.34	3.66
$CaSO_4$, per cent	2.18	2.57	0.56	3.26
$Ca(OH)_2$, per cent	53.10	58.43	92.36	52.73
$Mg(OH)_2$, per cent	33.38	3.37	.....	35.49
MgO, per cent	5.87	30.75	0.75	4.42
Excess CaO, per cent	...	...	1.55	...

2. Comparative tests with pressure hydrate showed that 1:1:6, by weight, sanded mixes gave approximately one eighth as much expansion as the corresponding 1:1 neat mixes.

3. In the case of the sanded bars cured for different periods before autoclaving, those made from regular dolomitic hydrate showed very little change in autoclave expansion over the 6-month period. On the other hand, bars made from pressure hydrate which gave very appreciable autoclave expansion after 1 day curing gave very small autoclave expansions after 6 months curing. Most of this decrease was evident after 3 days curing.

TABLE III.—EFFECT OF TIME AND PRESSURE ON PERCENTAGE OF AUTOCLAVE EXPANSION—LABORATORY NO. 3.

Type I portland cement used, 1 part of lime to 3 parts of cement by weight.

Lime Used	Autoclave Expansion, per cent			Consistency (normal), per cent[a]
	295 psi., 3 hr. (average)	100 psi., 3 hr. (average)	100 psi., 4 hr. (average)	
Dolomitic masons' pressure hydrate	0.072	0.074	0.079	31
Regular dolomitic finish	0.690	0.666	0.756	34
Dolomitic masons' pressure hydrate containing 12.5 per cent overburned material	0.101	0.079	0.088	32
High calcium masons' hydrate containing overburned material	0.063	...	0.032	39
Portland cement type I	0.051	...	−0.002	27

[a] Water in mix expressed as a percentage by weight of the dry cement-lime mixture.

4. No comments were made relative to any difficulties that might have been experienced with the autoclave test.

Laboratory No. 3

Laboratory No. 3 reported results of a limited number of tests comparing expansions of regular dolomitic and pressure hydrates and high-calcium hydrates (Table II).

All tests were made on neat mixes with ratios of cement to lime of 1:1 and 3:1. Test specimens were 1 by 1 by

10-in. bars. Effects of autoclaving for 3 hr. at 295 psi. and for 4 hr. at 100 psi. were compared (Table III). Effects of small variations in consistency also were determined (Table IV).

TABLE IV.—EFFECT OF CONSISTENCY ON PERCENTAGE OF AUTOCLAVE EXPANSION—LABORATORY NO. 3.

Type I portland cement used, 1 part of lime to 3 parts of cement by weight.

Specimens autoclaved 3 hr. at 295 psi.

Lime and Cement Used	Consistency		Expansion, per cent
	Water in Mix, ml. per 500 g.[a]	Water in Mix, per cent [b]	
Portland cement, type I	135	27	0.051
Dolomitic masons' pressure hydrate	155	31 (normal)	0.072
Dolomitic masons' pressure hydrate	160	32	0.070
Dolomitic masons' pressure hydrate	150	30	0.068
Regular dolomitic finish	170	34 (normal)	0.690
Regular dolomitic finish	175	35	0.736
Regular dolomitic finish	165	33	0.675

[a] Milliliters of water per 500 g. of dry cement-lime mixture.

[b] Water in mix expressed as a percentage by weight of the dry cement-lime mixture.

Results:

1. Owing to the high percentage of failures of specimens from 1:1 mixes this mix was discarded and all tests thereafter were made with mixes made of 25 per cent lime and 75 per cent cement.

2. Variations of consistency over a range of 2 per cent difference in water content did not appreciably affect the expansions.

3. Autoclaving for 4 hr. at 100 psi. produced approximately the same expansion as 3 hr. at 295 psi.

4. Changing the physical characteristics of a pressure hydrate by processing without changing appreciably the unhydrated oxide content, markedly changes the autoclave expansion (Fig. 4).

5. Autoclaving at 295 psi. in accordance with A.S.T.M. Method C 151 was adopted as a satisfactory *control* test for pressure hydrated lime.

Laboratory No. 4

Laboratory No. 4 reported a large volume of data obtained largely in an effort to determine the relation between autoclave tests or unhydrated oxide content and the functioning of white coats made from limes. Most of the autoclave tests, therefore, were made on a mix of four parts by weight of hydrated

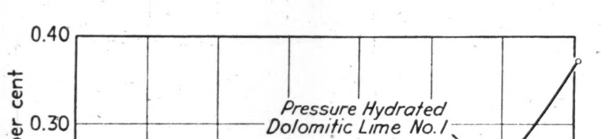


FIG. 4.—Autoclave Expansion of Neat Mixtures of Cement and Pressure Hydrated Limes of Different Physical Characteristics—Laboratory No. 3.

Specimens autoclaved for 3 hr. at 295 psi.

lime and one part of gaging plaster, the limes having been soaked for 24 hr. before use.

The test specimens were $\frac{5}{8}$ by $\frac{1}{2}$ by 8-in. bars which, after curing for 1 hr. at room temperature, were removed from the mold, dried in air for 16 to 20 hr., and then further dried for 24 hr. at 110 F. They were then autoclaved for 1 hr. at a steam pressure of 120 psi.

Parallel tests were made in which the same finish coats were applied to small restrained panels of brown coat 4 by 4-in. and 8 by 8-in. in dimensions and the panels cured and autoclaved in the same manner as the bars. The configuration of the brown coats were as conducive to blistering as it was possible to make them, consistent with practicability.

A smaller number of tests were also made on 1 by 1 by 10-in. bars of neat cement-lime mixes (1:1). Some of these bars were cured for 21 hr. in an atmosphere of saturated water vapor at 100 F., then air dried for 36 hr. and autoclaved for 1 hr. at 120 psi. The hydrated limes were soaked for 18 hr. before use. The dry hydrated limes contained varying amounts of unhydrated oxides, the desired unhydrated oxide content being obtained by mixing autoclaved hydrates and normal dolomitic hydrates of known analyses. Both normal and soft consistencies were tried.

Results:

1. As a result of the test with finish coats the investigators conclude that "In view of the severity of the autoclave test, which is generally recognized as being a greatly aggravated condition over that encountered in service, it seems that the autoclave test can be used to establish a safe limit of linear expansion for dolomitic finishing lime plaster. Tests on restrained panels of brown coat to which dolomitic finishing lime plasters were applied, the configuration of the brown coats being as conducive to blistering as it was possible to make them consistent with practicability, showed that blistering was not obtained in the usual autoclave test when the linear expansion of a corresponding bar of finish coat was less than 3.3 per cent or the unhydrated oxide content of the dolomitic lime used was less than 16.6 per cent.

"A dolomitic lime which, when made into a bar of finish coat, has a linear expansion of 3.0 per cent in the autoclave test (tested as described above) should give satisfactory service judging by the results obtained in this investigation. Similarly, a dolomitic finishing lime with an unhydrated oxide content of less than 16.0 per cent should be satisfactory.

"In general, there was no difference in the tendency to blister in 4 by 4-in. or 8 by 8-in. panels, provided blistering occurred in the smaller panels with relatively small percentages of normal hydrate, but blistering was more prone to occur in the large panels when it happened in 4 by 4-in. panels only with normal hydrate alone or with mixtures containing large percentages of normal hydrate.

"The results, in general, indicated that the tendency of finish coat to blister was not in direct proportion to the amount of unhydrated oxide content."

2. The results of tests of cement-lime mixes "in general, indicated that bars containing lime with less than 8 per cent of unhydrated oxide expanded only about 0.2 per cent in the autoclave test; the expansion increased markedly, however, when the unhydrated oxide content of the lime was greater than 8 per cent.

3. "The effect of initial consistency of the batch (cement-lime, neat) was slight when the limes had less than 15 per cent

of unhydrated oxides; bars made from stiff mixes had higher expansions than those made from soft ones when the unhydrated oxide content was above 15 per cent.

4. "The expansion of the bars (cement-lime) in the autoclave was not a linear function of the unhydrated oxide content. A marked increase in the rate of expansion was observed when there was 12 per cent of unhydrated oxides present. Above 12 per cent, expansion was a linear function."

Very considerable differences in degree of linear expansions were obtained in some cases in tests with different limes having the same unhydrated oxide content (above 8 per cent).

Laboratory No. 5

Laboratory No. 5 submitted autoclave expansion data on both neat and sanded mixes of cement and lime (1:1). In one series the limes used were obtained by autoclaving a regular dolomitic hydrate at 25 psi. steam pressure for different periods, and hence contained different percentages of unhydrated magnesia (Fig. 5).

Dolomitic quicklime putty and high-calcium hydrated limes were used in other tests.

Tests are also reported on bars that had been subjected to different degrees of carbonation before autoclaving (Table V, Fig. 6).

Test specimens were 1 by 1 by 4-in. bars. These were autoclaved for 8 hr. at 25 psi., and after removal from the autoclave were (apparently) cooled in air to room temperature.

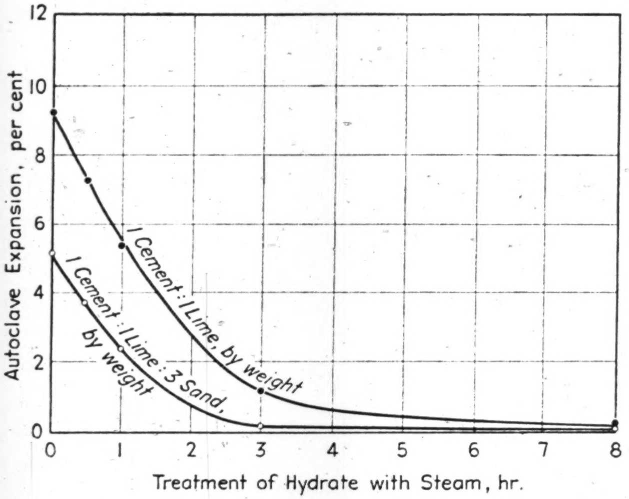


FIG. 5.—Autoclave Expansion for Specimens Made from Steam-Treated Hydrate—Laboratory No. 5.

Regular dolomitic hydrate treated with steam at 25 psi. before use in test specimens. Specimens autoclaved for 8 hr. at 25 psi.

Results:

1. The expansions obtained by autoclaving for 8 hr. at 25 psi. are, in general, appreciably less than the values reported by other investigators who autoclaved limes of comparable unhydrated oxide content at 295 psi. for 3 hr.

2. Sanded mixes in all cases showed much less expansion than the corresponding neat mixes.

3. Specimens which had been carbonated showed much less expansion than those which had not been carbonated before autoclaving.

TABLE V.—EFFECT OF DEGREE OF CARBONATION ON AUTOCLAVE EXPANSION—LABORATORY NO. 5.
1 part of regular dolomite hydrate to 3 parts of sand by weight.

Time of Exposure of Specimens to Laboratory Air Before Carbonation	Specimen Number	Carbonation Data			Autoclave Data (after 8 hr. at 25 psi.)		
		Number of Hours Carbonated	Original Weight, g.	Change in Weight, per cent	Change in Length, per cent	Change in Weight, per cent	Remarks
24 hr.	18	0	130.8	...	...	...	Decomposed
	10	10	128.7	+1.9	+2.4	...	Crumbly
	11	20	128.9	1.0	4.1	...	
	12	30	128.7	0.5	4.3	...	
	13	60	130.1	0.9	1.1	−1.7	No cracks
	14	100	132.3	2.5	1.0	−5.1	
7 days	6	0	118.1	...	...	...	Decomposed
	1	10	116.8	2.3	...	...	
	2	20	117.7	3.7	1.6	+5.1	Large cracks
	3	30	118.3	4.4	0.0	+1.1	No cracks
	4	60	119.4	6.1	0.0	−1.1	
	5	90	116.2	11.3	0.0	−3.0	
14 days	9	0	118.5	...	...	...	Decomposed
	7	10	119.2	1.7	...	...	
	8	20	116.6	2.7	1.6	...	Large cracks
	15	30	119.3	3.6	0.0	−3.2	No cracks
	16	50	120.4	3.9	0.0	−3.2	
	17	70	117.7	5.9	0.0	−4.9	

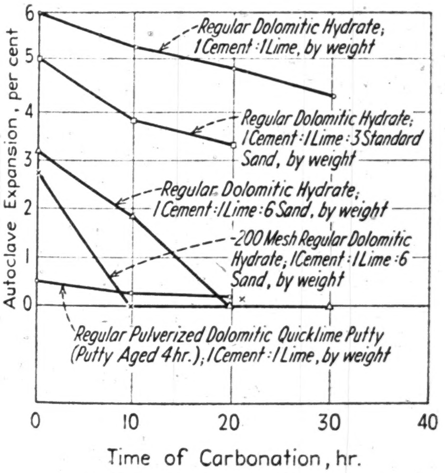


FIG. 6.—Relation of Autoclave Expansion to Degree of Carbonation Before Autoclaving—Laboratory No. 5.
Specimens autoclaved for 8 hr. at 25 psi.

Laboratory No. 6

Laboratory No. 6 reported data from autoclave expansion tests of seven limes. These comprised two regular dolomitic hydrates, two pressure hydrated dolomitic limes, one hydrate made from a specially burned dolomitic lime, and two high-calcium hydrates. Mixtures of limes were also tested in order to obtain a range of unhydrated oxide content (see Fig. 7).

Tests were largely limited to one cement but a limited number of tests were made on mixtures using seven other brands of cement.

All test specimens were 1 by 1 by 10-in. bars made from neat mixes. Most of the tests were with 1:1 mixes, although some were made with 2:1 and 3:1 cement-lime mixes. Only a few sanded mixes were tested.

One set of specimens was autoclaved at 295 psi. for 3 hr. with all conditions of curing and test the same as prescribed in A.S.T.M. Method C 151. A duplicate set was autoclaved at 120 psi. for 3 hr. all other conditions being the same.

Results:

1. Different limes having the same (relatively high) unhydrated oxide content gave widely different expansions. Different mixes obtained by diluting a

given lime with other limes so that the mixes compared had the same unhydrated oxide content also gave widely different expansions.

2. Appreciable differences in consistency of the mixes made inappreciable differences in the expansions.

The cement-lime mixes made from one of the pressure hydrated limes required so much water to give normal consistency that the shrinkage during curing caused cracking of a large percentage of the specimens. The procedure for determination of consistency specified in A.S.T.M. Method C 151 is not entirely satisfactory for mixes of high lime content.

3. Duplicate tests by two different operators yielded expansion figures that checked very closely.

4. Six of the eight cements (range of autoclave expansion 0.06 to 0.17 per cent gave mixes with the same lime which showed approximately the same expansions. One of the other two (expansion 0.38 per cent) in a mix with a lime having a relatively high unhydrated oxide content gave exceptionally high expansions, while the other cement (expansion 0.9 per cent) gave exceptionally low expansions. Three of the cements (expansions of 0.06, 0.13, and 0.16 per cent, respectively) produced mixtures with one of the pressure hydrated limes (5 per cent unhydrated oxides) which gave expansion values that checked very closely.

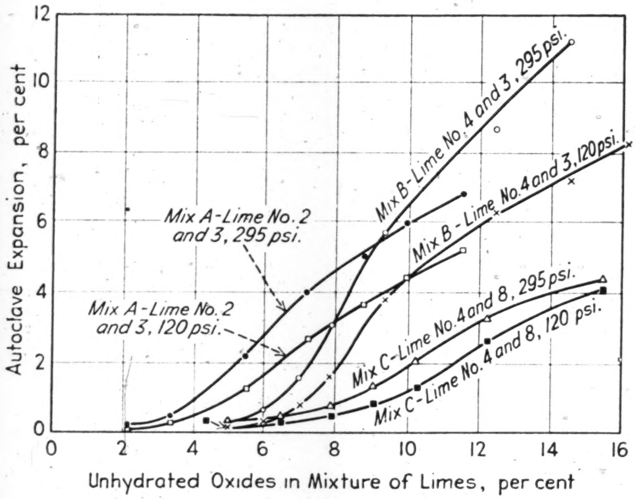


FIG. 7.—Relation of Autoclave Expansion to Percentage of Unhydrated Oxides in Several Mixtures of Limes—Laboratory No. 6.

Lime No. 2—High-calcium hydrate, 2.2 per cent unhydrated oxides.
Lime No. 3—Regular dolomitic hydrate, 27.4 per cent unhydrated oxides.
Lime No. 4—Pressure hydrated dolomitic lime, 5.0 per cent unhydrated oxides.
Lime No. 8—Special dolomitic hydrate, 36.6 per cent unhydrated oxides.

Mix proportions equal 1 part of cement to 1 part of lime by weight. Specimens cured for 24 hr. before autoclaving for 3 hr. at pressures of 295 and 120 psi.

The indications are that variations among cements which show autoclave expansions not over 0.2 per cent will not cause appreciable variations in the expansion values of 1:1 lime-cement mixes of relatively low expansions.

Laboratory No. 7

Laboratory No. 7 reported autoclave expansion figures on sanded mixes made from three different limes having 10, 18, and 28 per cent of unhydrated oxides, respectively. The cement-lime ratios in these mortars ranged from 95:5 to 50:50 by weight. All mortars were made with one part of cementitious material and two and one-half parts of standard Ottawa sand (passing a No. 20 (840-micron) and retained on a No. 30 590-micron sieve) by weight. The test specimens (1 by 1 by 10-in. bars) were autoclaved at 150 psi. for 2 hr. A duplicate set of specimens was stored in a moist room at 21 C. for 6 yr. and the expansion measured. A third set of similar specimens was stored out of doors for the same length of time.

Results:

The results and conclusions are stated by this laboratory as follows:

1. "Good correlation was obtained between autoclave expansion and expansion of the specimens stored 6 yr. in a moist condition, as can be seen by the following tabulation:

Autoclave Expansion, per cent	Expansion at 21 C., per cent
0.008	0.004
0.04	0.02
0.1	0.03
0.5	0.06
1.0	0.08
3.0	0.1
5.0	0.2
8.0	0.3 to 0.5

2. "Correlation was likewise good between free magnesia and expansion in damp storage.

3. "Specimens stored outdoors expanded more slowly and have now attained about two thirds of the expansion of the moist cured specimens."

GENERAL CONCLUSIONS

None of the data submitted by any two of the laboratories are strictly comparable, owing either to differences in the limes used or to differences in the conditions of test, and this appears to be the case with practically all of the autoclave work on limes that has ever been done previously. For this reason, it is impossible to draw definite conclusions as to the applicability of the autoclave test for determining the volume change characteristics of limes or to define a particular set of conditions of test.

From the data at hand there appears to be insufficient data showing correlation between autoclave expansion of a lime and its serviceability with respect to volume change of its mortars to justify the establishment of a maximum value for autoclave expansion by any test which might be selected. Only one of the reporting laboratories suggested such a limit. However, the following pertinent conclusions appear to be justified:

1. The autoclave expansion of specimens made from mixtures of lime and cement, or from lime and gaging plaster, is not a function of the unhydrated oxide content of the lime alone. Exact information is not available with respect to the effects of autoclaving on the chemical and physical characteristics of the combination of materials in question, and until this information is at hand the use of the autoclave will have to remain in the category of an arbitrary test that may be used for the want of a better one.

2. Theoretically, the use of the autoclave is justified in that it makes possible the measurement of the maximum potential expansion of the material under the conditions of the test. It also makes possible a comparison between different limes when exposed to these test conditions. Just as insufficient information is available to fix a value for maximum expansion, more information is needed as to what pressure should be used in the test. There is some justification in the use of the high pressure (295 psi.), except for the additional cost of the equipment, as this will result in the maximum ultimate expansion possible, and the equipment has been standardized for use at

this pressure. The fact that 295 psi. is considered a suitable pressure for autoclaving cement does not, however, prove that such a pressure would be suitable for use with lime.

3. The use of sanded mixes appears to offer no advantage over neat mixes. Since sanded mixes might be subject to possible pozzuolanic effects and to greater variations in uniformity of mix, it would seem that the testing of neat mixtures should be more satisfactory. A mixture of one part of lime and one part of cement by weight appears to be preferred by a majority of the reporting laboratories.

RECOMMENDATIONS

A review of the test data submitted indicates that it would be desirable to have additional information before any autoclave test for limes is adopted. It is therefore recommended:

1. That comparative tests be made by several different laboratories using a specified method of test on the same limes. For these tests duplicate samples of at least four pressure hydrated limes and one cement should be submitted. These limes should be of known unhydrated oxide content, and it would probably be preferable that an additional regular dolomitic hydrate be used as an admixture to increase the oxide content to study the effect of increasing unhydrated oxides with each lime.

Complete and detailed description of procedure should be given covering the mixture to be used and the methods to be followed in preparation, curing, and testing of the specimens. It is suggested that a 1:1 neat mix of cement and lime be used and that the procedure be the same as specified in the A.S.T.M. Standard Method of Test for Autoclave Expansion of Portland Cement (C 151 – 43),[1] with the exception that the time of mixing of the cement-lime paste should be specified as 3 min. instead of 1½ min. There should be included the additional requirement that the dry cement-lime mix shall be trowelled thoroughly before mixing with water in order to insure uniformity. Some limes are difficult to mix with cement.

Tests should be outlined to include at least three pressures for comparison.

These tests should indicate the degree of reproducibility of results as among different laboratories.

2. That efforts be made to get tests started which would be designed to obtain data from which it would be possible to determine what the correlation may be between the autoclave expansion of a lime and the serviceability of mortars made from the lime. Such data should make possible the establishment of a maximum limit for expansion by the autoclave test.

3. Inasmuch as Laboratory No. 2 found that appreciably different effects on the two different types of lime were produced by three days curing of the specimens before autoclaving, it might be well to obtain further data on autoclave expansions after curing specimens under various conditions.

Respectfully submitted on behalf of the special subcommittee,

H. R. STALEY, *Chairman.*

REPORT OF COMMITTEE C-8
ON
REFRACTORIES

Because of the war situation, Committee C-8 on Refractories held but one meeting during the year, at the Battelle Memorial Institute, Columbus, Ohio, on September 30, 1943. The committee, however, was active and various actions on standards were taken.

At the September meeting the committee reaffirmed its permanent policy that specifications shall be written for the selection of refractory materials for use in specific industries or applications rather than as applying to refractory products *per se*.

No new members were elected during the year, and there were no resignations.

I. NEW TENTATIVE STANDARD

The American Standards Association in June, 1943, approved a set of symbols pertaining to heat flow which appear in the American Standard Letter Symbols for Heat and Thermodynamics Including Heat Flow (Z10.4–1943). It is hoped that these symbols will become an international standard. Many of the symbols which Committee C-8 has adopted in the A.S.T.M. Standard Symbols for Heat Transmission (C 108 – 41)[1] are identical with those of the American Standard Z10.4, but in order to have all of them precisely the same and to include others which were not included in the past, the committee recommends that the present Standard Symbols C 108 be withdrawn and replaced by new Tentative Symbols for Heat Transmission,[2] which are identical with the letter symbols for heat flow in the American Standard Z10.4.

II. REVISION OF TENTATIVE STANDARD

Tentative Specifications for Air-Setting Refractory Mortars (Wet Type) for Boiler and Incinerator Services (**C 178 – 43 T**).[3] —Although the Tentative Specifications for Fireclay Plastic Refractories for Boiler and Incinerator Services (C 176 – 42 T) provide that, unless otherwise specified, high heat duty plastic refractories shall be supplied, Specifications C 178 do not include a similar clause. The committee, therefore, recommends that Specifications C 178 be revised by the addition of the following sentence to Section 1 on Scope: "Unless otherwise specified, high heat duty mortar shall be supplied."

III. TENTATIVE REVISIONS OF STANDARDS

Standard Method of Test for Pyrometric Cone Equivalent (P.C.E.) of Refractory Materials (**C 24 – 42**).[4]—In replies received from a questionnaire circulated to laboratories which regularly make P.C.E. tests, the opinion was nearly unanimous that a standard test cone mold should be described in this method. A drawing was prepared for the excess-length type of split mold, and Committee C-8 recommends that this drawing as shown in the accompanying Fig. 1

---

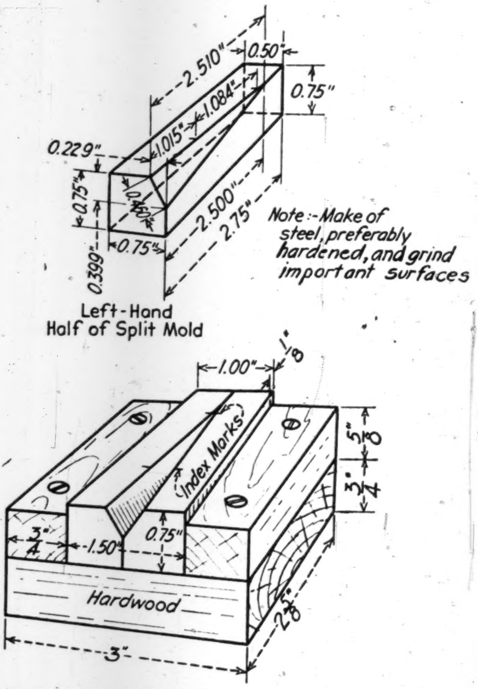
[1] 1942 Book of A.S.T.M. Standards, Part II, p. 288.

[2] These symbols were accepted as tentative by the Society and appear in the 1944 Book of A.S.T.M. Standards, Part II, p. 1312.

[3] 1943 Supplement to Book of A.S.T.M. Standards Part II, p. 85.

[4] 1942 Book of A.S.T.M. Standards, Part II.

be published as a tentative revision of Standard Method C 24.



Note:-Make of steel, preferably hardened, and grind important surfaces

Left-Hand Half of Split Mold

Note:-Index marks show the length of the short side of the cone

Mold Assembly

FIG. 1.—Split Mold for A.S.T.M. Pyrometric Test Cone.

Standard Specifications for Ground Fire Clay as a Mortar for Laying-Up Fireclay Brick (**C 105 — 41**).[4]—These specifications do not carry a provision for resampling and retesting when requested either by the purchaser or the manufacturer. Such provisions are made in other specifications. The committee therefore recommends the following for publication as tentative revision of Specifications C 105:

Retests.—Add the following as a new Section 7, renumbering the present Section 7 as Section 8:

> 7. *Retests.*—Because of variables resulting from sampling and the lack of perfect reproducibility in tests conducted by different laboratories, resampling and retesting may be carried out when requested by either the purchaser or the manufacturer. This may apply in instances where the first test result does not conform to the limits prescribed in these specifications. The final result to be used for each test shall be the average of the original and the retest figures.

TENTATIVE STANDARD ADOPTED AS STANDARD

The committee recommends that the Tentative Specifications for Fireclay Plastic Refractories for Boiler and Incinerator Services (C 176 – 42 T)[4] be approved for reference to letter ballot of the Society for adoption as standard.

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 37 members, with the results shown in Table I.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. NEW TENTATIVE STANDARD			
Symbols for Heat Transmission	24	0	2
II. REVISION OF TENTATIVE STANDARD			
Spec. for Air-Setting Refractory Mortars (Wet Type) for Boiler and Incinerator Services (C 178 – 43 T)	24	0	2
III. TENTATIVE REVISIONS OF STANDARDS			
Test for Pyrometric Cone Equivalent (P.C.E.) of Refractory Materials (C 24 – 42)	25	0	1
Spec. for Ground Fire Clay as a Mortar for Laying-Up Fireclay Brick (C 105 – 41)	24		2
IV. ADOPTION OF TENTATIVE STANDARD AS STANDARD			
Spec. for Fireclay Plastic Refractories for Boiler and Incinerator Services (C 176 – 42 T)	31	0	3

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Industrial Survey (L. C. Hewitt, chairman) has surveys still in progress on the refractories used for water-gas generators, and in the oil industry, but because of the times difficulties have been experienced in getting them completed. The following new survey projects have been initiated: (*1*) W. S. Debenham, of Carnegie-Illinois Steel Corp., is undertaking the revision of the survey on open-hearth refractories; (*2*) W. C. Rueckel, of Koppers Co., will revise the survey of by-product coke ovens in order to incorporate present-day practice; (*3*) G. L. Oldright, U. S. Bureau of Mines, Rolla, Mo., is rewriting the present lead survey. A survey relating to steel-mill pouring-pit refractories is planned.

Subcommittee II on Research (S. M. Phelps, chairman) was inactive during the past year, as no projects had been suggested by the committee.

Subcommittee III on Tests (F. A. Harvey, chairman) is composed of the chairmen of the several sections described below. The activities of the subcommittee are discussed under the individual sections. The chairman of each section is reviewing the test methods which come under his jurisdiction in order to ascertain whether the necessary apparatus and equipment have been described adequately and in sufficient detail in the test methods in the Manual of A.S.T.M. Standards on Refractory Materials.

Section B on Spalling (R. E. Birch, chairman) is considering how it can make use of the subject matter in the Recommended Practice for the Panel Spalling Test as issued by the Refractories Fellowship, Mellon Institute. This literature was prepared to supplement the information given in the A.S.T.M. Methods of Panel Test for Resistance to Thermal and Structural Spalling of Refractory Brick (C 38 – 42), of High Heat Duty Fireclay Brick (C 107 – 42), and of Super Duty Fireclay Brick (C 122 – 42), and as a guide not only to construction but also in the operation of the panel spalling equipment. It has been distributed to all those who have built the spalling equipment. Much of the subject matter might well be incorporated in the present test methods or issued as a suggested practice. The Section on Spalling was requested to take this suggestion under consideration to learn of portions which might be used and the form in which it might be presented in the literature of Committee C-8.

Section C on Temperature (R. B. Sosman, chairman) circulated a questionnaire concerning pyrometric cones and test cone molds to laboratories which regularly make P.C.E. tests. The purpose of this questionnaire was to find out whether current practice is in agreement with the Standard Method of Test for Pyrometric Cone Equivalent (P.C.E.) of Refractory Materials (C 24 – 42) in regard to the position of the cone at the end point, and to obtain suggestions for a suitable mold. The section recommended the proposed tentative revision in Standard Method C 24 previously discussed.

Future work planned by the section includes having cone 32½ standardized by the National Bureau of Standards.

Work is being done in various laboratories on the effect of atmosphere and means of controlling the air-fuel ratio in P.C.E. furnaces. The Section on Temperature hopes to present additional data at a later time on the comparison of electric *versus* gas-air heated furnaces.

Section E on Analysis (L. J. Trostel, chairman) is making editorial changes in the Standard Methods of Chemical Analysis of Refractory Materials (C 18 – 41) so that all references to standard potassium permanganate solution will be worded in the same manner.

Section F on Tests on Refractory Insulation (W. R. Kerr, chairman) has under consideration a suggestion to recommend to the Subcommittee on Classifications to include in the Tentative Classification of Insulating Back-Up Block and Insulating Fire Brick (C 155 –

41 T) brick which will withstand temperatures higher than the maximum limit of the present classification, that is, group 28. There are on the market a few brands bearing the number 30, which implies that such brick are good for service at temperatures in the neighborhood of 3000 F. At the September meeting it was the consensus that there were no data available on the behavior of those few brands on the market bearing identification numbers above 28, and that no attempt should be made to extend the classification above the present limits until there are on the market products which comply with the permanent linear change and bulk density requirements of higher temperature classes. This section and Subcommittee IX on Classifications will report further on this matter at the next meeting of Committee C-8.

The section has under consideration making the wording of the test procedures uniform in the Standard Methods of Testing Insulating Fire Brick (C 93 – 42), Tests for Permanent Linear Change After Reheating of Refractory Brick (C 113 – 36), and Cold Crushing Strength and Modulus of Rupture of Refractory Brick and Shapes (C 133 – 39) where the same procedure is being described.

Section G on Porosity and Permanent Volume Change (C. E. Fulton, chairman) recommended editorial changes in the Standard Method of Test for True Specific Gravity of Burned Refractory Materials (C 135 – 40). Since the method is applicable to materials which are not necessarily burned, the section proposed to eliminate the word "Burned" from the title. The section also proposed major modifications in Section 3. These suggested changes are now under consideration by the Subcommittee on Tests, and probably will be presented to the committee for action at the next meeting.

Committee C-8 approved a recommendation of the section that a note be inserted editorially under Section 12 (*b*) of the Standard Methods of Test for Apparent Porosity, Water Absorption, Apparent Specific Gravity, and Bulk Density of Burned Refractory Products (C 20 – 41) to give the conversion factor of grams per cubic centimeter to pounds per cubic foot. The note will read as follows:

NOTE.—The values for bulk density determined according to Section 12 will be expressed in metric units, for example, grams per cubic centimeter. The bulk density, however, determined by the direct measurement method will be expressed in English units. The conversion from metric to English units may be calculated as follows:

Bulk density in g. per cu. cm. × 62.43 = Bulk density in lb. per cu. ft.

Subcommittee IV on Heat Transfer (R. H. Heilman, chairman) has continued, through its member, C. L. Norton, the investigations on the apparatus for measuring thermal conductivity of insulating fire brick. Norton has modified the original equipment, but these developments have not advanced to the point and have not been tested sufficiently to justify a revision of the Tentative Method of Test for Thermal Conductivity of Insulating Fire Brick (C 182 – 43 T) at this time.

Method C 182 describes only the essential features of the apparatus and the methods of carrying out the test. In this respect it follows the general scheme adopted for the panel spalling test, and, as in the case of the latter, a suggested practice manual is needed. Such a manual is under preparation and should be ready for presentation at the next meeting of Committee C-8.

Subcommittee V on Precision and Tolerance (R. A. Heindl, chairman) was inactive during the year.

Subcommittee VI on Nomenclature (M. E. Holmes, chairman) is attempting to prepare definitions for air-setting refractory mortar (wet and dry types) and for heat-setting refractory mortar, to replace the present general definition entitled "high-temperature bonding mortar." The subcommittee is also considering a definition for fireclay plastic refractories.

Subcommittee VII on Specifications (G. A. Bole, chairman) recommended the tentative revision of the Standard Specifications for Ground Fire Clay as a Mortar for Laying-Up Fireclay Brick (C 105 - 41) and the revision of the Tentative Specifications for Air-Setting Refractory Mortars (Wet Type) for Boiler and Incinerator Services (C 178 - 43 T), both of which are submitted for action, as indicated earlier in this report.

In connection with Specifications C 178 the subcommittee has suggested that the test methods be separated from the specifications so as to follow the methods of presentation used in all the other specifications under the jurisdiction of Committee C-8. In addition a Section on Sampling is being prepared for Specifications C 178 similar to that contained in Specifications C 105.

A proposal for new specifications to cover ground clays other than those used as a mortar for laying up fireclay brick, and classified according to grades, particle size, and refractoriness, is being studied.

Subcommittee VIII, Editorial (L. J. Trostel, chairman).—A new edition of the Manual of A.S.T.M. Standards on Refractory Materials was issued in June, 1943. This complete manual has a total of 201 pages, and covers the following:

Specifications,
Classifications,
Methods of Testing,
Definitions,
Standard Samples,
Industrial Surveys, and
Procedure for Calculating Heat Losses.

Various editorial changes, previously mentioned, are under study by the subcommittee.

Subcommittee IX on Classifications (S. M. Swain, chairman) is studying suggestions for revisions in the Standard Classification of Fireclay Refractories (C 27 - 41) and the Tentative Classification of Insulating Back-Up Block and Insulating Fire Brick (C 155 - 41 T).

On the recommendation of R. H. Heilman, representative of Committee C-8 on a Section of the ASA Committee on Scientific and Engineering Materials, some of the symbols for heat flow appearing in ASA Z10.4–1943 are being submitted for publication as an A.S.T.M. tentative standard to replace the Standard Symbols for Heat Transmission (C 108 - 41), as covered earlier in this report.

As the committee did not hold a Spring Meeting this year, the election of officers for the ensuing term of two years was conducted by letter ballot vote of the membership of the committee and resulted in the selection of the following:

Chairman, J. D. Sullivan.
Vice-Chairman, L. J. Trostel.
Secretary, S. M. Phelps.

This report has been submitted to letter ballot of the committee, which consists of 37 members; 31 members returned their ballots, all of whom voted affirmatively.

Respectfully submitted on behalf of the committee,

J. D. SULLIVAN,
Chairman.
L. J. TROSTEL,
Vice-Chairman.

S. M. PHELPS,
Secretary.

REPORT OF COMMITTEE C-9

ON

CONCRETE AND CONCRETE AGGREGATES

Committee C-9 on Concrete and Concrete Aggregates held one meeting during the year, in Pittsburgh, Pa., on March 28, 1944. After an interval of comparative inactivity, due to the war, the subcommittees of Committee C-9, particularly those dealing with standards, became unusually active and Subcommittees VII, IX, XIII, XVII, and XVIII met in Chicago, Ill., on March 2 and 3, 1944. This resulted in action being taken at the March meeting of Committee C-9 on a large number of recommendations which are being submitted to the Society in this report. The committee, through its subcommittees, has made special efforts to review and bring up to date the several standards under its jurisdiction.

The committee submits as an Appendix to this report a paper by J. C. Pearson on "Volumetric Method for Determining the Air Content of Freshly Mixed Concrete." This paper is sponsored by Subcommittee VII on Methods and Apparatus for Testing Concrete and was prepared by Mr. Pearson as an assignment from that subcommittee.

No report is made at this time on election of officers for the ensuing term of two years since, by special action at the March meeting, this election will be held at the June meeting during the Annual Meeting of the Society.

Subsequent to the 1943 Annual Meeting, Committee C-9 presented to the Society, through Committee E-10 on Standards, revised Specifications for Ready-Mixed Concrete for publication as tentative to supersede Specifications C 94 – 42 T. This recommendation was accepted[1] by the Standards Committee on October 25, 1943, and the revised specifications appear in the 1943 Supplement to Book of A.S.T.M. Standards, Part II, bearing the designation C 94 – 43 T.

Sanford E. Thompson Award.—The Sanford E. Thompson award for a paper of outstanding merit on concrete and concrete aggregates, established in 1938 in honor of the first chairman of the committee, will be made this year to Douglas McHenry for his paper on "A New Aspect of Creep in Concrete and Its Application to Design," which was presented at the 1943 Annual Meeting. This is the fourth Sanford E. Thompson award, previous awards having been made in 1942, 1941, and 1940.

I. NEW TENTATIVE STANDARD

The committee recommends for publication as tentative a new Method for Making and Curing Concrete Compression and Flexure Specimens in the Laboratory,[2] to replace those sections of Methods C 39 and C 78 dealing with making and curing the specimens.

---

[1] In submitting this recommendation to Committee E-10 on Standards, Committee C-9 reported the following results of the letter ballot vote of a total of 62 ballots returned from a committee membership of 74: Affirmative 55, negative 3, and 4 ballots marked "not voting."

[2] This method was accepted as tentative by the Society and appears in the 1944 Book of A.S.T.M. Standards, Part II.

II. REVISION OF TENTATIVE STANDARDS

Tentative Method of Test for Efficiency of Materials for Curing Concrete (**C 156 - 40 T**).[3]—The committee recommends that this method be revised as appended hereto,[2] and continued as tentative.

Tentative Method of Test for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate (**C 88 - 41 T**).[3]—The committee recommends that this method be revised as follows and continued as tentative:

Section 1.—Change the section on scope to read as follows by the addition of italicized words and the omission of those in brackets:

> 1. This method covers the procedure to be followed in testing aggregates to determine their resistance to disintegration by saturated solutions of sodium sulfate or magnesium sulfate. It furnishes information helpful in judging [of] the soundness of aggregates subject[ed] to weathering action, *particularly when adequate information is not available from service records of the material exposed to actual weathering conditions.* [In selecting aggregates, consideration should be given to service records of the materials when exposed to actual weathering conditions over a period of at least 5 yr., but, in the absence of such information, the test method should be used as the basis of acceptance or rejection of the material. Either or both of these methods may be used. However,] Attention is called to the fact that [the] test results by the use of the two *salts* [methods] differ considerably and care must be exercised in fixing proper limits in any specifications which may include requirements for these tests.

Section 6.—Change the first sentence of Paragraph (*a*) to read as follows by the addition of the italicized words and figures and the omission of those in brackets: "The samples shall be immersed in the prepared solution of sodium sulfate or magnesium sulfate for *not less than 16 hr. nor more than 18 hr.* [at least 16 hr.] in such a manner that the solution covers them to a depth of at least ½ in."

Change the first sentence of Paragraph (*b*) to read as follows by the addition of the italicized words and the omission of the letter in brackets: "After the immersion period the aggregate sample[s] shall be removed from the solution, *permitted to drain*, and placed in the drying oven."

Section 9 (*c*).—Add the following sentence to this paragraph: "In these calculations sizes finer than the No. 50 sieve shall be assumed to have 0 per cent loss."

III. REVISION OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends for immediate adoption, revisions in nine of its standards, as set forth below, and accordingly asks for a nine-tenths affirmative vote at the Annual Meeting in order that these modifications may be referred to letter ballot of the Society:

Standard Specifications for Concrete Aggregates (**C 33 - 42**):[3]

Soundness.—Add a new Section 6 on Soundness to read as follows, renumbering the subsequent sections accordingly:

6. *Soundness*.—Fine aggregate shall pass a sodium or magnesium sulfate accelerated soundness test, except that aggregates failing in the accelerated soundness test may be used if they pass a satisfactory freezing-and-thawing test.

Section 9.—In the column heading change "Unit weight" to read "Compact weight."

Section 10.—In the first sentence, change "sodium sulfate accelerated soundness test" to read sodium or magnesium sulfate accelerated soundness test."

Section 11.—Revise this section to include a reference to the Standard Method of Test for Clay Lumps in Aggregates (C 142 - 39).

Standard Method of Test for Structural Strength of Fine Aggregate Using Constant Water-Cement-Ratio Mortar (**C 87 - 42**):[3]

Section 3.—Change the first sentence of Paragraph (*a*) to provide for a ½-in. drop instead of a ⅛-in. drop.

---

[3] 1942 Book of A.S.T.M. Standards, Part II.

Change the second sentence of Paragraph (*b*) to provide for 10 drops in 10 sec. instead of 30 drops in 30 sec.

Standard Method of Test for Compressive Strength of Concrete Using Portions of Beams Broken in Flexure (Modified Cube Method) (**C 116 - 42**):[3]

Section 1.—Add the following note to this section:

> NOTE.—For the method of making the flexural strength test, see the Standard Method of Test for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading) (A.S.T.M. Designation: C 78).

Section 3.—Replace the present note by the following:

> NOTE.—Neat portland or alumina cement and suitable mixtures of sulfur with granular materials are recognized as suitable for capping hardened concrete specimens. Sulfur cap should be allowed to harden for at least 1 hr. before applying load; cement caps for a sufficient period to comply with the requirements prescribed in Paragraph (*b*).

Section 4 (*a*).—After the fourth sentence add the following additional sentence: "If the depth of the beam is not equal to the width, the contact faces shall be square and shall have the same dimensions as the width of the beam as tested."

Standard Method of Test for Coal and Lignite in Sand (**C 123 - 39**):[3]

Section 2 (*d*).—In the first sentence change the requirement for the wire gauze or sieve to provide for thirty openings per inch instead of six.

Section 3.—Change the third sentence from its present form: namely,

> The sample shall then be poured slowly into about 250 ml. of carbon tetrachloride (sp. gr. about 1.58) contained in one of the 400-ml. beakers.

to read as follows:

> The sample shall then be poured slowly into about 250 ml. of a liquid having a specific gravity of 2.0 contained in one of the 400-ml. beakers.
>
> NOTE.—Such a liquid can be prepared from an appropriate mixture of carbon tetrachloride and acetylene tetrabromide or bromoform and monobromo-benzene.

Change the seventh sentence from its present form: namely,

> The decanted particles contained on the gauze or sieve will dry very quickly, but may be placed in an oven at 105 C. for a few minutes if desired.

to read as follows:

> The decanted particles contained on the gauze or sieve shall be washed in carbon tetrachloride, until the flotation liquid is removed, and then dried. The particles will dry very quickly, but may be placed in an oven at 105 C. for a few minutes if desired.

Elsewhere in this section change "carbon tetrachloride" to read "liquid."

Standard Method of Making and Storing Compression Test Specimens of Concrete in the Field (**C 31 - 42**).[3]—The revised method entitled Method of Making and Curing Compression and Flexure Test Specimens of Concrete in the Field is appended.[4] As the new title indicates the method has been expanded to cover specimens for flexure as well as for compression tests. This revised method was completed subsequent to the March meeting of the committee and was submitted to letter ballot in accordance with the procedure provided in Section 14 (*b*) of the Society's Regulations Governing Standing Committees.[5]

Standard Method of Test for Compressive Strength of Concrete (**C 39 - 42**).[3]—The revised method entitled Method of Test for Compressive Strength of Molded Concrete Cylinders[4] covers that portion of Method C 39 which deals with the actual testing. That portion of Method C 39 which deals with the preparation and curing of test specimens is being recommended for publication in a separate method, as mentioned earlier in this report.

Standard Methods of Securing and Test-

---

[4] These revised methods were accepted as standard by the Society and appear in the 1944 Book of A.S.T.M. Standards, Part II.

[5] 1944 A.S.T.M. Year Book, p. 379.

ing Specimens of Hardened Concrete from the Structure (**C 42 – 42**).[3]—The revised methods entitled Methods of Securing, Preparing, and Testing Specimens from Hardened Concrete[4] have been expanded to take into account specimens for flexure tests as well as compression tests.

Standard Method of Test for Flexural Strength of Concrete (Laboratory Method Using Simple Beam with Third Point Loading) (**C 78 – 39**).[3]—The revised method entitled Method of Test for Flexural Strength of Concrete (Using Simple Beam with Third Point Loading)[4] covers that portion of Method C 78 which deals with testing. The remaining portion of Method C 78 referring to the preparation and curing of specimens is being recommended for publication in a separate method, as mentioned earlier in this report.

Standard Method of Test for Yield of Concrete (**C 138 – 39**).[3]—The revised method entitled Method of Test for Weight Per Cubic Foot, Yield, and Air Content of Concrete[4] represents a rewriting and rearrangement of Method C 138, and an expansion to cover a method for calculating the air content of freshly mixed concrete from the weight per cubic foot.

IV. REVISION OF STANDARD, AND REVERSION TO TENTATIVE

The committee recommends that the following standard be revised and reverted to tentative:

Standard Method of Test for Surface Moisture in Fine Aggregate (**C 70 – 30**).[3]—The revised method[2] represents a major revision of Method C 70. It provides for the use of a variety of types of measuring devices, whereas the present Method C 70 is limited in scope as to the apparatus which may be used.

V. ADOPTION OF TENTATIVE STANDARDS AS STANDARD

The committee recommends that the following three tentative standards be approved for reference to letter ballot of the Society for adoption as standard, without revision:

Tentative Methods of:[3]

Sampling Fresh Concrete (C 172 – 42 T),
Measuring Length of Drilled Concrete Cores (C 174 – 42 T), and
Tentative Definitions of Terms Relating to Concrete and Concrete Aggregates (C 125 – 42 T), this recommendation not having been considered at the March meeting is submitted to letter ballot in accordance with the procedure provided in Section 14 (*b*) of the Society's Regulations Governing Standing Committees.

The committee also recommends that the Tentative Specifications for Ready-Mixed Concrete (**C 94– 43 T**)[6] be approved for reference to letter ballot of the Society for adoption as standard, revised as indicated below:

Section 3 (*b*).—Change to read as follows by the addition of the italicized words and the omission of those in brackets: "Admixtures, *if to* [may] be used, *shall be* [only when specifically] provided for in the contract or in the designated applicable specifications for [the] concrete."

Table I.—Change the title of this table to read as follows by the omission of the words in brackets: "Compressive Strengths of [Ready-Mixed] Concrete Suitable for Various Conditions of Exposure."

Change the note at the head of this table to read as follows by the addition of the italicized words: "NOTE.—*Presented as information only and not as a part of the specifications*; adapted from Tables 1 and 2 of the Report of the Joint Committee on Standard Specifications for Concrete and Reinforced Concrete, June, 1940."

Section 5.—Throughout this section change "the maximum and minimum slump specified" to read "the specified maximum and minimum slumps."

Section 8.—In Paragraph (*d*) change the word "batch" to read "load."

---

[6] 1943 Supplement to Book of A.S.T.M. Standards, Part II.

Change Paragraph (*f*) from its present form: namely,

> (*f*) Mixers and agitators shall be examined daily for freedom from hardened concrete or mortar and for condition of blades due to wear. When any such condition is found to be questionable the tests described in Paragraph (*d*) should be repeated.

to read as follows:

> (*f*) Mixers and agitators shall be examined daily for changes in condition due to accumulations of hardened concrete or mortar or to wear of blades. When any such change of condition is found the tests described in Paragraph (*d*) should be repeated.

Section 9.—Beginning with the second sentence of Paragraph (*b*), start a new Paragraph (*c*) and reletter the remaining paragraphs accordingly.

Change the first sentence of the present Paragraph (*f*) (to be relettered as (*g*)) from its present form: namely,

> Concrete shall be delivered to the site of the work and discharge from the truck mixer or agitator shall be completed within 1½ hr. after the introduction of the mixing water to the cement and aggregates, or the cement to the aggregates, except that in hot weather, or under other conditions contributing to quick stiffening of the concrete, the maximum allowable time may be reduced by the purchaser.

to read as follows:

> Concrete shall be delivered to the site of the work and discharge from the truck mixer or agitator shall be completed within 1½ hr. after the introduction of the mixing water to the cement and aggregates, or the cement to the aggregates, unless a longer time is specifically authorized by the purchaser. In hot weather, or under conditions contributing to quick stiffening of the concrete, a time less than 1½ hr. may be specified by the purchaser.

Sections 11 and 12.—In the last sentence of these two sections change the word "batch" to read "load."

Section 14.—In Paragraph (*a*) change the phrase "tests shall be made" to read "standard tests (see Section 17) shall be made;" also change "batches" to read "loads."

In Paragraph (*c*) change the word "batch" to read "load."

VI. ADOPTION OF TENTATIVE REVISION OF STANDARD AS STANDARD

The committee recommends that the tentative revisions[6] (with the exception of the explanatory note) submitted in June, 1941, in the Standard Method of Test for Abrasion of Coarse Aggregate by Use of the Los Angeles Machine (C 131 – 39)[3] which provide for abrasion tests of finer gradings of mineral aggregates be approved for reference to letter ballot of the Society for adoption as standard. This recommendation is presented jointly with Committee D-4 on Road and Paving Materials.

VII. WITHDRAWAL OF TENTATIVE STANDARD

The committee recommends that the Tentative Method of Test for Soundness of Aggregates by Freezing and Thawing (C 137 – 38 T)[3] be withdrawn. The reason for this action is that the method departs greatly from the procedures which have been adopted by most laboratories doing freezing and thawing work; it is believed that the method needs to be completely rewritten to take into account current best practices and that the current method should accordingly be withdrawn at this time.

VIII. TENTATIVE STANDARDS CONTINUED AS TENTATIVE

The committee recommends that the following specifications and methods of test be continued as tentative without change:

Tentative Specifications for:

Waterproof Paper for Curing Concrete (C 171 – 42 T),

Tentative Methods of Test for:

Air Content of Freshly Mixed Concrete (C 173 – 42 T), and

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. NEW TENTATIVE STANDARD			
Method for Making and Curing Concrete Compression and Flexure Specimens in the Laboratory	60	2	3
II. REVISION OF TENTATIVE STANDARDS			
Test for Efficiency of Materials for Curing Concrete (C 156 - 40 T)	54	2	6
Test for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate (C 88 - 41 T)	59	2	4
III. REVISION OF STANDARDS, IMMEDIATE ADOPTION			
Spec. for Concrete Aggregates (C 33 - 42)	61	0	2
Test for Structural Strength of Fine Aggregate Using Constant Water-Cement-Ratio Mortar (C 87 - 42)	60	1	2
Test for Compressive Strength of Concrete Using Portions of Beams Broken in Flexure (Modified Cube Method) (C 116 - 42)	54	1	8
Test for Coal and Lignite in Sand (C 123 - 39)	56	1	6
Method of Making and Storing Compression Test Specimens of Concrete in the Field (C 31 - 42)	59	0	3
Test for Compressive Strength of Concrete (C 39 - 42)	62	0	0
Methods of Securing and Testing Specimens Hardened Concrete from the Structure (C 42 - 42)	62	0	0
Test for Flexural Strength of Concrete (Laboratory Method Using Simple Beam with Third Point Loading) (C 78 - 39)	60	0	2
Test for Yield of Concrete (C 138 - 39)	54	2	6
IV. REVISION OF STANDARD, AND REVERSION TO TENTATIVE			
Test for Surface Moisture in Fine Aggregate (C 70 - 30)	60	1	2
V. ADOPTION OF TENTATIVE STANDARDS AS STANDARD			
Methods of Sampling Fresh Concrete (C 172 - 42 T)	62	0	1
Methods of Measuring Length of Drilled Concrete Cores (C 174 - 42 T)	58	1	4
Def. of Terms Relating to Concrete and Concrete Aggregates (C 125 - 42 T)	59	2	2
Spec. for Ready-Mixed Concrete (C 94 - 43 T), as revised	57	0	6
VI. ADOPTION OF TENTATIVE REVISION OF STANDARD AS STANDARD			
Test for Abrasion of Coarse Aggregate by Use of the Los Angeles Machine (C 131 - 39 ASA A 37.7-1943)	61	0	2
VII. WITHDRAWAL OF TENTATIVE STANDARD			
Test for Soundness of Aggregates by Freezing and Thawing (C 137 - 38 T)	58	1	4
VIII. TENTATIVE STANDARDS CONTINUED AS TENTATIVE			
Spec. for Waterproof Paper for Curing Concrete (C 171 - 42 T)	50	0	13
Method of Test for Air Content (Volumetric) of Freshly Mixed Concrete (C 173 - 42 T)	58	0	5
Method of Test for Abrasion of Gravel by Use of the Deval Machine (D 289 - 42 T)	57	0	6

Abrasion of Gravel by Use of the Deval Machine (D 289 - 42 T), under the joint jurisdiction of Committee C-9 and Committee D-4 on Road and Paving Materials.

IX. STANDARDS SIX YEARS WITHOUT REVISION

The committee recommends that the following standards which have been published as standard for six or more years without revision be continued as standard:

Standard Specifications for:

Sodium Silicate for Curing Concrete (C 111 - 36),

Standard Methods of Test for:

Voids in Aggregate for Concrete (C 30 - 37),
Organic Impurities in Sands for Concrete (C 40 - 33), and
Amount of Material Finer than No. 200 Sieve in Aggregates (C 117 - 37), under the joint jurisdiction of Committee C-9 and Committee D-4.

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 74 voting members, with the results shown in Table I.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, F. E. Richart.
Vice-Chairman, K. B. Woods.
Secretary, Stanton Walker.
Chairman of Finance Subcommittee, H. J. Love.

Members-at-Large of Advisory Committee:

R. F. Blanks	A. T. Goldbeck
H. F. Clemmer	F. H. Jackson
M. N. Clair	J. C. Pearson
R. W. Crum	C. E. Wuerpel

This report has been submitted to letter ballot of the committee which consists of 74 voting members; 63 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

F. H. JACKSON,
Chairman.

STANTON WALKER,
Secretary.

APPENDIX

VOLUMETRIC METHOD FOR DETERMINING THE AIR CONTENT OF FRESHLY MIXED CONCRETE

REPORT TO SUBCOMMITTEE VII ON METHODS AND APPARATUS FOR TESTING CONCRETE

PREPARED BY J. C. PEARSON[1]

One of the projects of Subcommittee VII, assigned to the author, is that of developing a method for determining the air content of fresh concrete better adapted for field use than the Tentative Method of Test for Air Content of Freshly Mixed Concrete (C 173 – 42 T),[2] which involves weighings of unusual accuracy.

After some discussion of this problem in our laboratory, it was felt that a volumetric method offered the most promise, as it involves no weighings and requires no knowledge of proportions or physical properties of cement and aggregates. It was thought that a rather large pycnometer of at least 0.2-cu. ft. capacity would be suitable if built in the form of a 6-in. diameter cylinder, 12 in. or more in height, and surmounted by a cone with a small opening at the top. The cone should be detachable to permit introducing the sample of concrete, and should provide means of being attached quickly in such manner as to give a water-tight joint.

In operation, a measured volume of concrete would be placed in the pycnometer, and an equal or somewhat larger measured volume of water would be added. The cone would then be replaced, and the concrete and water thoroughly mixed to displace the air. Finally, the amount of water necessary to fill up the cone would be determined, and the volume of air would be given by the relation

$$V_a = V_w - (V_p - V_m) \ldots\ldots (1)$$

where:

V_a = volume of air entrained in the concrete,

V_w = total volume of water required to fill up the pycnometer,

V_p = volume of the pycnometer, and

V_m = volume of the measure filled with concrete.

The values of V_p and V_m would be known from calibration, and the percentage air would be

$$P_a = 100\ V_a/V_m \ldots\ldots\ldots (2)$$

The apparent difficulties that might be anticipated were:

(*a*) The measured concrete would have to be transferred to the pycnometer without loss.

(*b*) If a considerable amount of foam or scum developed in the de-airing process, it would have to be reduced in some way to permit accurate determination of the amount of water required to fill the pycnometer.

(*c*) The de-airing process should remove the entrained air completely.

(*d*) All water used should be accurately accounted for.

---

[1] Director of Research, Lehigh Portland Cement Co., Allentown, Pa.

[2] 1942 Book of A.S.T.M. Standards, Part II, p. 1203.

(*e*) Effects of changes in temperature should be determined and compensated, if necessary.

DESCRIPTION OF PYCNOMETER AND ITS OPERATION

As the principles involved in the volumetric air determination are quite clear, the above-mentioned difficulties may now be discussed in connection with the details of the pycnometer and its operation. Figure 1 shows the scheme of the instrument as used in the study reported herewith. It is made from a 13-in. length of drawn brass tubing, 6 in. in inside diameter. Instead of having the cone *C* detachable from section *B*, the tube was cut at the line *XY*, providing a bottom section *A*, 6 in. high. This section has a volume of very nearly 0.1 cu. ft. and its use as a measure for the concrete obviously eliminates the first difficulty mentioned above. This measure is usually filled by the standard method for weight per unit volume of concrete, but the weight is not needed for the air determination. After the measure is accurately filled, the concrete is pushed back from the rim with a spatula, and the rim is wiped clean. Section *B* is then placed on section *A* and made tight with four small bolts. Details of the joint are shown in Fig. 2.

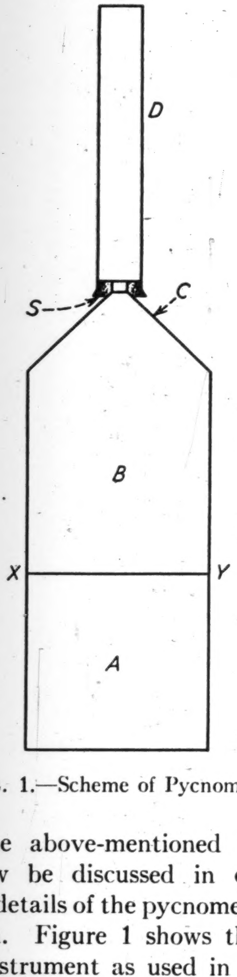


FIG. 1.—Scheme of Pycnometer.

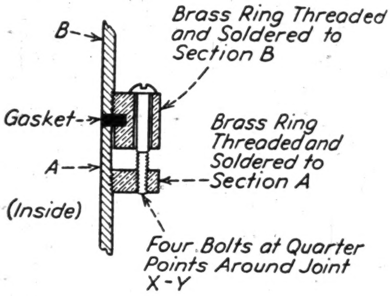

B
Brass Ring Threaded and Soldered to Section B
Gasket
Brass Ring Threaded and Soldered to Section A
A
(Inside)
Four Bolts at Quarter Points Around Joint X-Y

FIG. 2.—Detail of Joint at *Y*.

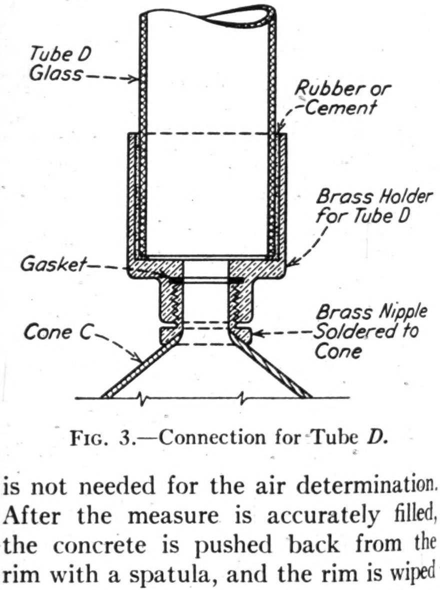

Tube D Glass
Rubber or Cement
Brass Holder for Tube D
Gasket
Brass Nipple Soldered to Cone
Cone C

FIG. 3.—Connection for Tube *D*.

The next operation is to pour 3 liters of water into the pycnometer, add 1 to 2 ml. of a defoaming agent (2-ethyl hexanol was used in our work), stopper the opening at the top, and thoroughly mix water and concrete by turning the pycnometer end for end 30 times. The water thus displaces the air in the concrete, and if there is no foam or scum resulting from the operation, the pycnometer can be filled to the top with a measured amount of water and the air determined by Eq. 1. In general, however, this cannot be done because more or less foam is formed in the de-airing operation, and whenever an air-entraining cement containing Vinsol resin is used a persistent scum develops which is quite unaffected by ordinary defoaming agents.

SOLUTION OF THE SCUM PROBLEM

All difficulties encountered in the development of this volumetric method faded into insignificance in comparison with that of finding a way to evaluate the scum. This material may be defined as a very fine-bubble foam, consisting of air, water, fine cement particles, and insoluble soapy solids, so stable that it will stand in a closed glass jar for many weeks without apparent change. No defoaming agents or chemicals were found that would reduce it, at least in a practical way, and the only effective method, known to the author, of de-airing the material is by vacuum treatment. Fortunately this can be done with a good aspirator capable of reducing the pressure in a suction flask to about 1 in. of mercury. This method was used successfully in the laboratory to de-air the scum and to get its equivalent in liquid volume, but such a method would hardly be practical in the field. Therefore, a series of experiments were undertaken to find some means of collecting the scum so that its volume could be measured and an estimate made of its de-aired volume.

The simplest solution found for this problem was the use of a graduated glass tube *D* mounted on top of the pycnometer, as shown in Fig. 1. This tube was made by sawing off the ends of an ordinary 250-ml. graduate to give a usable capacity of about 200 ml., and was attached to the top of the pycnometer with a rubber stopper *S*. A more suitable connection is detailed in Fig. 3. The necessity for using this auxiliary tube detracts somewhat from the simplicity of the device for use in the field, but it is needed only at the end of the air determination and does not have to stand rough treatment.

Before describing the evaluation of the scum, let us complete the steps of the operation. When the air has been removed from the concrete in the pycnometer by thorough mixing with 3 liters of water, the tube *D* is attached, and the fourth liter of water is poured in at the top of the tube. If the percentage of air does not exceed 4 or 5 per cent, these 4 liters of water are usually enough (for our pycnometer) to float the scum up into the tube. If the air content is higher than 4 or 5 per cent, more water may be needed to raise the scum column to a convenient height for reading its top and bottom boundaries. A 100-ml. graduate serves to keep track of the added water used. If now a factor can be used to reduce the scum volume to equivalent liquid volume, and this, plus the liquid in the tube below the level of the scum, is subtracted from the total water used, we finally arrive at the volume of water required to fill the pycnometer, and the percentage of air can be determined by Eqs. 1 and 2.

Evaluation of Scum:

In the laboratory, when the top and bottom of the scum column had been read on tube *D*, the scum was transferred to a suction flask with a longstemmed syringe, and with added, carefully measured water, all the scum was removed, the syringe rinsed into the flask, and the level of the water brought back to the reading at the bottom of the scum column. Thus all the additional water used, plus that in the scum, was now in the flask. With the aspirator attached, the scum in the flask was then completely de-aired, and the residual liquid measured in a suitable graduate. The excess of this liquid over that of the rinse water used was taken as the volume of the de-aired scum.

COMPLETENESS OF AIR REMOVAL FROM CONCRETE

Not all the scum in the pycnometer rises into the tube *D* of its own accord. When water has been added in sufficient quantity to bring the scum column into the tube, the pycnometer should be tilted at an angle of 30 to 45 deg. from the vertical, slowly rotated by hand on the edge resting on the table, and the pycnometer continuously and smartly tapped with a wooden hammer. This dislodges air and scum adhering to the underside of the cone, and tends to free the last remaining bubbles in the slurry below. This process usually requires from 1 to 5 min. depending upon the quantity of scum, and must be continued until no further rise of air or scum is noted against the upper side of the inclined glass tube. This is one point in favor of the tube because it enables the operator to see even the last small traces of air rising from the pycnometer. The device is then righted to its vertical position, the scum leveled as nearly as possible, and the glass tube gently tapped until all the flocculated material has dropped away from the bottom of the scum column, and the interface is sharp and clear.

ERROR IN MEASUREMENT OF WATER

The error in measurement of water is really quite small if ordinary care is taken in reading the measures used, allowing time for drainage of adhering water, and avoiding accidental loss. The liter flask used in these experiments was found to deliver 999 ml. under normal use, and a reasonable error from this source should hardly amount to 0.1 per cent in the air determination.

EFFECT OF TEMPERATURE CHANGES ON VOLUME MEASUREMENTS

The coefficient of thermal expansion of water is variable, but many times larger than that of most solids. Hence, if any correction for temperature differences is necessary, it would be confined to effects on the measured volume of water. Since the volume change would be dependent on the temperature of the water when measured and the temperature of the water in the pycnometer when the final readings were made, it is recommended that these temperatures be always recorded, as well as the temperature of the concrete when it is measured at the beginning of a test. For temperature differences likely to be encountered, however, it may be shown that the error is small in comparison with other errors, and can generally be disregarded except in those cases where increased accuracy is desirable.

To indicate how the temperature correction should be made, suppose that water and concrete are at the same temperature, *T*, and that a volume of water, *V*, is required to fill the pycnometer even full. Now if *V* were measured at a higher temperature than *T*, its value at *T* would be less than *V*, and more water would have to be added to fill the pycnometer. This additional water would appear to indicate that the air content of the concrete was *greater*, and therefore the correction to the apparent air content would be subtractive. If it were desired to correct also for the change in temperature of the concrete, which would rise if water warmer than the concrete was used, the expansion of water in the concrete would necessitate less being added to fill the pycnometer, and this would appear to indicate *lower* air content in the concrete, so that the correction from this source would be additive. As examples of such corrections, mixes Nos. 12, 13, and 14 in Table I were made. In mix No. 12 the tests were made at 21 C. (70 F.) and the air contents by Method C 173 – 42 T (using vacuum) and by the volume pycnometer (laboratory value) were 6.7 and 6.8 per cent, respectively. In mix No. 13, the temperature of the concrete was 22 C. (72 F.), and Method C 173 – 42 T, carried out as before, gave 6.9 per cent air. In the volumetric determination the added water was measured at 35 C. (95 F.) and the temperature of the mixture at the end of the test was 30 C. (86 F.). The change in specific volume of water from 35 C. to 30 C. is 0.001634 ml. per ml., and for the approximately 4000 ml. of water used, the change in volume would be −6.5 ml. The change in specific volume from 22 C. to 30 C. is 0.002138 ml. per ml. and for the approximately 500 ml. of water in the measured volume of concrete, the change

TABLE I.—DATA OF TESTS FOR AIR DETERMINATION.

Mix	Concrete Data		Scum Data			Percentage of Air in Concrete					
						By Volume Method		By Method C 173 - 42 T		Computed From	
	Weight, lb. per cu. ft.	Net Water, gal. per cu. yd.	Volume of Scum, ml.	Volume of De-Aired Scum, ml.	Percentage of Water in Scum	Laboratory Value	Job Value	Using Vacuum	Without Vacuum	Unit Weight	Absolute Volumes
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
No. 1	138.4	31.6	59	23	39	7.6	7.7	7.5	7.5	8.2	7.1
No. 2	143.8	33.8	22	7	32	3.8	3.8	3.8	3.8	4.2	3.1
No. 3	137.4	32.0	148	52	35	8.2	8.1	7.8	7.8	8.9	7.6
No. 4	142.8	32.9	35	11	31	4.6	4.5	5.1	5.0	4.9	4.0
No. 5	143.6	33.5	25	8	32	4.1	4.0	4.2	4.2	4.3	3.4
No. 6	142.2	33.5	59	22	37	5.3	5.3	5.2	5.0	5.4	4.2
No. 7	140.0	32.7	80	31	39	6.8	6.9	6.4	6.1	7.0	5.8
No. 8	144.3	33.6	19	6	32	3.7	3.7	4.1	4.1	3.8	3.0
No. 9	145.6	34.6	15	6	40	2.9	2.9	3.2	3.2	2.9	1.8
No. 10	142.3	32.3	53	19	36	5.9	5.9	5.5	5.5	5.3	4.6
No. 11	141.1	31.8	70	29	41	6.3	6.5	6.2	6.0	6.2	5.4
No. 12[a]	140.5	31.9	73	27	37	6.8	6.8	6.7	6.4	6.6	5.8
No. 13[a]	140.0	31.4	93	37	40	7.0	7.1	6.9	6.9	7.0	6.2
No. 14[a]	139.8	31.3	86	34	40	6.8	6.9	7.0	6.9	7.1	6.4
No. 15	142.2	31.7	45	17	38	5.6	5.6	5.5	5.3	5.4	4.8
No. 16[b]	146.8	35.6	4	2	..	1.7	1.7	1.9	2.0	2.0	0.8
No. 17	139.6	30.7	76	27	36	7.3	7.3	7.5	7.4	7.3	6.7
No. 18	140.9	31.0	78	29	37	6.4	6.4	6.2	6.2	6.3	5.7
No. 19	144.8	34.4	25	8	32	3.4	3.4	3.3	3.4	3.5	2.4
No. 20	138.7	31.8	96	37	39	7.6	7.6	7.8	7.4	7.9	6.9
No. 21	143.1	33.7	39	13	33	4.8	4.7	4.8	4.8	4.7	3.6
No. 22	137.4	31.3	102	34	33	8.6	8.5	8.5	7.8	8.9	7.8
No. 23	137.6	31.6	112	38	34	8.5	8.4	8.4	8.3	8.7	7.5
No. 24	139.6	30.5	86	29	34	7.8	7.7	7.2	7.0	7.2	6.7
No. 25	135.6	28.5	150	51	33	10.6	10.5	10.3	9.7	10.2	9.8
No. 26[c]	131.4	27.6	...	..	..	13.1	(13.1)	13.2	12.3	13.3	12.5
No. 27	137.1	29.3	109	37	34	9.3	9.2	9.6	8.8	9.1	8.6
No. 28	133.3	28.2	178	59	33	11.9	11.6	11.7	11.3	11.9	11.2
Average values					36	6.7	6.6	6.6	6.4	6.7	5.8

[a] Mixes Nos. 12, 13, and 14 were the same, except that water used in the volumetric determination of mix No. 13 was at 95 F., while that in mix No. 14 was at 50 F. See discussion of temperature effects on page 10.

[b] Scum volume too small to be evaluated by vacuum application.

[c] Scum volume larger than capacity of measuring tube.

in volume was +1.1 ml. The net correction was therefore −5.4 ml., which made a difference of −0.2 per cent in the air content. The value for air content without regard to temperature was computed at 7.2 per cent, and the corrected value was 7.0 per cent. In mix No. 14 the standard method gave 7.0 per cent air; in the volumetric method the concrete was mixed at 22 C. (72 F.), the water was added at 10 C. (50 F.) and the temperature of the mixture at the end was 16 C. (61 F.). Following the same procedure as indicated above, the air content computed without regard to temperature was 6.7 per cent, and the corrected value was 6.8 per cent. These examples show about what order of error is made by disregarding temperature changes of considerable magnitude.

RESULTS OF TESTS

Table I summarizes the essential data from 28 concrete mixtures tested by Tentative Method C 173, and by the volumetric method described herein, after the latter was in essentially its final form as illustrated. In these mixtures the same proportions of cement and aggregates were used throughout, but the water was varied to produce a nominal slump of 4 ± $\frac{1}{2}$ in. Mixes were all made in a small Lancaster mixer according to a strict time schedule both as to time of mixing and to addition of water. The concrete was such that if made with average type I cement, it would contain about 6 bags of cement per cubic yard, and would have a water ratio of about 6 gal. per sack. Owing to the wide variation in air contents, the yields were correspondingly different, and the cement contents varied from 5.25 to 5.8 sacks per cubic yard. The first ten mixtures of Table I were made with ten different air-entraining commercial cements; the remainder were made, with a few exceptions, from the same clinker ground in a laboratory mill together with various forms and quantities of Vinsol resin. These mixtures were made for a more general study of the effects of Vinsol resin, but they were admirably suited for checking the performance of the volumetric method for air because of their wide range in air content.

COMPARISON OF AIR DETERMINATIONS BY THE STANDARD AND VOLUMETRIC METHODS

Table I includes some data that are not strictly a part of the criteria for the volumetric method, but are related to the general subject of air in concrete. First, therefore, let us discuss the data pertaining to the subject of this report. Columns 4 and 5 contain the scum volumes as measured in the pycnometer tube, and after de-airing under vacuum treatment as previously described. Column 6 gives the percentage of water (and solids) in the scum, by volume, and it is seen that the figures vary from 32 to 41 per cent as determined, with an average value of 36 per cent. Toward the end of the series it was discovered that the bottom of the scum column rises slowly upon standing, especially if the volume of the scum is large, and the later the reading is made the nearer the de-aired volume approaches the value of 33 per cent. This takes possibly 10 or 15 min. for the higher scum volumes, and to avoid this delay, the factor 0.36 can be used if one waits only until the bottom line of the scum becomes clear and the flocculated material has settled away from it. However, it is a very comforting fact that a variation of 1 or 2 per cent in this scum factor makes little difference in the air determinations, as shown by the values in columns 7 and 8. The figures in column 7 are the air percentages as determined from the actual volumes of liquid in the de-aired scum, while those in column 8 are computed as they would be in the field, using the constant reduction factor of 36 per cent applied to the observed volumes of scum. The greatest difference between the laboratory and job values is 0.3 per cent.

To indicate how nearly the air contents determined by this method agree with those determined by the standard method, all mixtures were tested simultaneously by the two methods, the derived values being based on the concrete as rodded into the bottom section of the pycnometer. To obtain some additional data on the effect of vacuum treatment as applied to the standard method, the latter was subjected to only two washing tests, and then all the scum and fine cement that had been removed was returned to the pycnometer and vacuum was applied previous to the final weighing. It is seen from a comparison of columns 9 and 10 that there is practically no difference in the values up to about 7 per cent of air, but considerable additional air was removed by vacuum treatment from some of the mixes containing still higher air contents. However, this difference is more apparent than real, for the standard method specifies that the weighings shall be repeated until a difference not greater than 2 g. shall be obtained, and this was not done in these tests because of the extra time required and the consequent interference with the schedule. Therefore the vacuum treatment was taken as giving the correct figure, and the comparisons of the two methods are quite satisfactory. Nevertheless it is reassuring that the standard method would probably be found to give values very nearly in agreement with those obtained by vacuum treatment over the whole range of air contents, if the determinations were made as specified.

Based on experience with the standard method and the volumetric method in this investigation it is the conviction of our operators that the volumetric method gives nearly as dependable results for air content of fresh concrete as the standard method, and has the advantage of taking less time and requiring much less computation. For field use the entire equipment can be carried in a small handbag and the operator needs only a piece of plank or a flat slab and a bucket of water to set himself up in business.

FORM FOR RECORDING TEST DATA

The following form for recording observations and computing air contents of concrete will assist in making all essential notes in proper sequence. The values given are from a typical case (No. 1 in Table I). The form does not include provision for computing effects of temperature, which require a table of specific volumes for water and do not need to be computed in the field except possibly under extreme conditions.

Observations	1. Volume of concrete measure (V_m)	2782 ml.
	2. Volume of upper section ($V_p - V_m$)	3781 ml.
	3. Temperature of concrete	20 C. (68 F.)
	4. Temperature of water at start	21 C. (70 F.)
	5. Total volume of water used	4098 ml.
	6. Zero reading of tube (at top of pycnometer)	46
	7. Reading of top of scum column in tube	188
	8. Reading of interface (bottom of scum column in tube)	129
	9. Temperature of water in pycnometer at end of test	21 C. (70 F.)
Computations	10. Volume of scum, (7) − (8)	59 ml.
	11. Liquid in scum, 0.36 × (10)	21 ml.
	12. Liquid in tube below interface, (8) − (6)	83 ml.
	13. Total liquid in tube, (11) + (12)	104 ml.
	14. Water to fill pycnometer, (5) − (13)	3994 ml.
	15. Volume of air in concrete, (14) − (2)	213 ml.
	16. Per cent air in concrete, 100 × (15) ÷ (1)	7.7 per cent

APPENDIX—ADDITIONAL MISCELLANEOUS INFORMATION

Since the weight per unit volume of all concretes was determined in these tests, it was possible to compute air content from *a general formula* derived from the tests. When the weights per cubic foot of the concretes were plotted against air contents, a linear relation was indicated, and the equation of the line best representing the locus of the points was found to be

$$\text{per cent air} = 0.735 \times (149.5 - \text{wt. of concrete per cu.ft.}) \ldots (3)$$

Using this formula the air contents (in per cent) were determined from the data in column 2 of Table I, and are listed in column 11. The generally close agreement of these values with those given in column 9 shows how closely the weights per cubic foot reflect the air content of the concrete. While the constants in Eq. 3 would be different for different types of concrete, the equation might be used as a basis for approximation of air content when the weight per cubic foot of the concrete was known, and particularly if the weight of the concrete with zero air content (corresponding to the constant 149.5 in Eq. 3) could be determined from known weights and specific gravities of concrete ingredients.

It was observed in these tests that the water content of the concrete at constant slump decreased as the air content increased. Therefore, the net water in gallons per cubic yard as listed in column 3 of Table I was plotted against air content, and again a very good linear relation was indicated. The equation of the line best fitting the points was determined as

$$\text{net water, gal. per cu. yd.} = 36.8 - 0.74 \times \text{per cent air} \ldots (4)$$

This shows a reduction in water content of about $\frac{3}{4}$ gal. per cu. yd. for each 1 per cent of air in the concrete. This reduction in water content is between 0.13 and 0.14 gal. per sack for each 1 per cent of air in the concrete. Again, these figures would apply only to concretes similar to those used in this investigation, but might be taken as a general basis for rough estimates of the effect of entrained air on water content for a given consistency.

Since the specific gravities and absorptions of the aggregates used in these tests were known, the air contents of the 28 concretes were computed by the summation of absolute volumes, these values being given in column 12 of Table I. It is seen that the air contents so computed are on the average about 0.8 per cent less than those determined by the standard method or by the volumetric method. This difference may be due in part to small errors in specific gravity of aggregates, but the properties of these aggregates are well known and the errors in specific gravities are hardly likely to be great enough to account for differences in air determinations of nearly 1 per cent. All things considered, it is believed that air determinations by this method are likely to be in considerable error and less dependable than direct determinations by the volumetric method.

DISCUSSION

MR. CHARLES E. WUERPEL.[1]—Our one criticism of the method proposed by Mr. Pearson is the small size of the container. Most of the concrete placed by the Corps of Engineers contains a maximum size aggregate of at least 2-in. and the 0.1 cu. ft. measure is too small to use with such concrete. I should like to ask Mr. Pearson the question as to why the size of the measure could not be increased.

MR. J. C. PEARSON.[2]—The answer is that this device was designed as a one-man apparatus, to be handled without too much effort. It is true that the 0.1 cu. ft. measure is undesirably small for concrete containing 2-in. aggregate. One would then have a choice of making one or more repeat determinations with this device or of using a larger container, the latter probably requiring some mechanical equipment for the de-airing operation.

MR. WUERPEL.—The second comment I should like to make is that we are reassured to see as close a check between the proposed method and the so-called unit weight method, because it gives us a little bit more confidence in the use of the unit weight method, which we believe is simpler to perform in the field. Mr. Pearson's method is workable in the field, but certainly with the type of inspector that we have to live with in the field, it is a lot easier to give him a unit weight measure with a semblance of the standard puddling rod and a set of scales, and get reasonably good results than it would be to hope to get very accurate results with Mr. Pearson's method, which has certainly additional requirements, including the correction factor.

The difference of 1 per cent, I really believe, constitutes a good check. It's too bad it isn't a flat check. But we consider the 1 per cent as a pretty good check especially in the range of air contents which occur in field concrete.

MR. PEARSON.—The main objection to the unit weight method is the uncertainty in regard to specific gravities and proportions of ingredients in job concrete. If these are known with accuracy, the unit weight method is the simplest, and should give satisfactory air determinations. Otherwise the air determinations will be in error by an unknown and possibly large amount.

MR. WUERPEL.—It is perfectly true that accurate knowledge of the specific gravity is necessary with the unit weight method. One of the most admirable points of Mr. Pearson's method is that, as he says, you do not have to know the "pedigree" of the concrete. Of course, I question the desirability of having to deal with concrete when the "pedigree" is unknown. As we try to increase the technical aspect of the technology of concrete, we should know more about this pedigree than we do, and in all of our work at any rate we do everything we can to supply the field with the specific gravity and the other data which are important to know in the control of the concrete, not only for its air content but also for its basic control of quality.

---

[1] Engineer-in-Charge, Central Concrete Laboratory, Corps of Engineers, U. S. Army, Mount Vernon, N. Y.

[2] Director of Research, Lehigh Portland Cement Co., Allentown, Pa.

REPORT OF COMMITTEE C-12
ON
MORTARS FOR UNIT MASONRY

Committee C-12 on Mortars for Unit Masonry has held no meeting since the 1942 Annual Meeting of the Society for obvious reasons. Interest in mortar has continued, however, as shown by the following papers presented at the 1942, 1943, and 1944 Annual Meetings, respectively:

"Curing of Masonry Mortars"[1] by Howard R. Staley,

"Measurement of Bond Between Bricks and Mortar,"[2] by J. C. Pearson, and

"The Effects of Certain Variations in Consistency and Curing Conditions on the Compressive Strengths of Cement-Lime Mortars,[3] by G. J. Fink.

Of particular interest is the American Standard Building Code Requirements for Masonry (A41.1–1944), approved and issued by the American Standards Association early in 1944. That the specifications for masonry mortar in this code are, in essence, the specifications that have been considered by Committee C-12 for the past several years, is not surprising in view of the fact that Committee C-12 and Sectional Committee A41 have about one quarter of their memberships in common.

The membership of Committee C-12 at present totals 31, of whom 13 are classified as producers, 7 as consumers, and 11 as general interest members.

I. REVISION OF TENTATIVE STANDARD

The committee recommends that the Tentative Specifications for Mortar for Reinforced Brick Masonry (C 161–41 T) be revised as appended hereto,[4] and continued as tentative.

This recommendation has been submitted to letter ballot of the committee which consists of 31 members; 23 members returned their ballots of whom 19 have voted affirmatively, 0 negatively, and 4 members marked their ballots "not voting."

II. ADOPTION OF TENTATIVE STANDARD AS STANDARD

The committee recommends that the Tentative Specifications for Aggregate for Masonry Mortar (C 144 – 42 T)[5] be approved for reference to letter ballot of the Society for adoption as standard.

This recommendation has been submitted to letter ballot of the committee which consists of 31 members; 23 members returned their ballots, all of whom have voted affirmatively.

ACTIVITIES OF SUBCOMMITTEES

With the exception of Subcommittee III on Specifications and Methods of Test for Mortar and Subcommittee IV on Specifications for Aggregate, no reports of subcommittees have been received since the 1942 meeting.

---

[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 42, p. 762 (1942).

[2] *Proceedings*, Am. Soc. Testing Mats., Vol. 43, p. 857 (1943).

[3] See p. 780.

[4] These specifications were accepted as tentative by the Society and appear in the 1944 Book of A.S.T.M. Standards, Part II, p. 1256.

[5] 1942 Book of A.S.T.M. Standards, Part II.

Subcommittee III on Specifications and Methods of Test for Mortar (H. C. Plummer, acting chairman).—This committee has prepared a revision of the Tentative Specifications for Mortar for Reinforced Brick Masonry (C 161 - 41 T) through a working subcommittee, consisting of H. C. Plummer (chairman), D. E. Parsons, and M. O. Withey. The revision includes added requirements relating to quality of materials, such as limitations on the use of admixtures, and antifreeze compounds, the addition to the proportion specifications of volume proportions for the convenience of the user, and a number of other changes. These changes, in general, are for the purpose of bringing the specifications into agreement with accepted good practice and with recent laboratory studies. Subcommittee III adopted these revisions unanimously and the revised specifications, appended hereto,[4] have been submitted to letter ballot of the committee.

Subcommittee IV on Specifications for Aggregate (Stanton Walker, chairman).—Since no criticism of the Tentative Specifications for Aggregate for Masonry Mortar (C 144 - 42 T) has been received since its publication, Subcommittee IV voted unanimously to recommend the adoption of the specifications as standard and this recommendation has also been submitted to letter ballot of the committee.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, Theodore I. Coe.
First Vice-Chairman, J. W. Whittemore.
Second Vice-Chairman, H. D. Baylor.
Secretary, Harry C. Plummer.

This report has been submitted to letter ballot of the committee which consists of 31 members; 23 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

J. W. McBurney,
Chairman.

H. C. Plummer,
Secretary.

REPORT OF COMMITTEE C-14
ON
GLASS AND GLASS PRODUCTS

Committee C-14 on Glass and Glass Products held one meeting during the year in Pittsburgh, Pa., on April 5, 1944.

Subcommittee VII on Glass Containers, although quite new, has established a Section A on Pharmaceutical Containers. Work is already under way between Subcommittee III on Chemical Properties and Section A of Subcommittee VII on the chemical durability of certain glasses.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Nomenclature and Definitions (F. C. Flint, chairman)—The Tentative Definition of the Term Glass (C 162 - 41 T) has been reviewed, revised, and submitted to the special subcommittee of Committee E-8 on Nomenclature and Definitions for consideration and comment.

Subcommittee III on Chemical Properties (J. F. Greene, chairman).—Three proposed tentative methods for determining chemical durability of glass have been developed. Subcommittee III is now submitting them to Subcommittee VII and its Section A for consideration and acceptance. The proposed tentative methods are as follows:

Test A.—Chemical Durability of Glass Used for Manufacture of Glass Containers. Glasses of the soda-lime type are crushed and subjected to attack by water or dilute acid at 90 C.

Test I.—Chemical Durability of Glass Containers. Glass containers of the soda-lime type are filled with water or dilute acid and subjected to a temperature of 120 C. in an autoclave.

Test II.—Chemical Durability of Glass Containers. Glass containers of the soda-lime type are filled with water or dilute acid and subjected to a temperature of 90 C.

In all three cases the amount of alkali extracted under the conditions of test are determined by titration.

Subcommittee VI on Glass Construction Block and Tile (J. P. Staples, chairman).—In order to further the work of this subcommittee it is necessary to define the term "glass tile," and to consider the inclusion within the scope of this subcommittee of other glass products used for structural purposes, such as cellular glass and thick glass plates.

Subcommittee VII on Glass Containers (W. R. Lester, chairman).—The ring-section method of examining glass containers for cord with polarized light, as worked out by the Glass Container Association is being considered for publication as tentative.

Subcommittee VIII on Flat Glass (F. W. Adams, chairman).—Since the likelihood of bombing of American cities during this war has diminished greatly, the first problem of this subcommittee, which was set up to make studies of the effect of bombing on flat glass, has been removed. The committee now plans to review all specifications dealing with flat glass, looking toward the preparation of proposed tentative methods to cover them.

Publication of Glass Standards in One Volume.—A desire has been expressed to include in one volume all the test methods dealing with glass. These would include standards originating in Committee C-14 as well as in other committees, and would cover insulators and textile materials. It would be desirable to have an approved up-to-date definition of glass in this volume and consideration is now being given to its preparation.

Tests on glass insulators are now being handled by Section C of Subcommittee V of Committee D-9 on Electrical Insulating Materials. Consideration is now being given to the suggestion that jurisdiction over this work be transferred to Committee C-14.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, Louis Navias.
Vice-Chairman, E. W. Tillotson.
Secretary, S. R. Scholes.

This report has been submitted to letter ballot of the committee which consists of 49 members; 35 members returned their ballots, of whom 33 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the committee,

J. C. HOSTETTER,
Chairman.

LOUIS NAVIAS,
Secretary.

REPORT OF COMMITTEE C-15 ON MANUFACTURED MASONRY UNITS

Committee C-15 on Manufactured Masonry Units held a meeting in Pittsburg, Pa., on June 30, 1943, during the Annual Meeting of the Society.

Subsequent to the 1942 Annual Meeting, Committee C-15 presented to the Society through Committee E-10 on Standards the following recommendations, which were accepted[1] on August 24, 1942, and appear in the 1942 Book of A.S.T.M. Standards, Part II:

Tentative Revisions of Standards:

Methods of Sampling and Testing Brick (C 67 – 41), comprising a Method of Test for Efflorescence of Brick (C 67 – 42 T), and

Specifications for Hollow Load-Bearing Concrete Masonry Units (C 90 – 39).

I. Revision of Tentative Standard

Tentative Specifications for Glazed Building Units (**C 126 – 39 T**).[2]—Extensive revisions of these specifications have been under consideration by the subcommittee during the past two years. The proposed revisions were submitted to Committee C-15 about one year ago and are now recommended for publication as tentative. They are so comprehensive that the specifications were rewritten, and the proposed revised specifications are appended hereto.[3] In addition to editorial changes, the revised specifications include such new features as requirements for ceramic glazed units of two grades and two types, for the important elements of shape and design, and for tolerances on dimensions and warping. Requirements for compressive strength were added and those for absorption were revised. Only minor revisions were made in the methods of testing.

II. Adoption of Tentative Standard as Standard

Tentative Specifications for Building Brick (Made from Clay or Shale) (**C 62 – 41 T**).[2]—The committee recommends that these tentative specifications be approved for reference to letter ballot of the Society for adoption as standard without revision.

III. Adoption as Standard of Tentative Revisions of Standards

Specifications for Hollow Load-Bearing Concrete Masonry Units (**C 90 – 39**).[2]—The committee recommends that the tentative revision[2] of Section 3, submitted in August, 1942, which provides for an increase in the compressive strength of units exposed to the weather and for compliance with the absorption requirements irrespective of the nature of the exposure, be approved for reference to letter ballot of the Society for adoption as standard without revision.

Methods of Sampling and Testing Brick (**C 67 – 41**).[2]—The tentative revision,[2] submitted in June, 1942, and modified August, 1942, is a proposed addition published in the Tentative Method of Test for Initial Rate of Absorption (Suction) and Efflorescence on Brick (C 67 – 42 T). The committee recommends that the tentative revision be approved for reference to letter ballot of the Society for adoption as standard with a change in the tolerance for the water level revising the present value "0.0025 in." to read "0.01 in." in Section 1 (*c*), Note 1, and Section 3 (*d*).

---

[1] In submitting these recommendations to Committee E-10 on Standards, Committee C-15 reported the following results of the letter ballot vote of a total of 40 ballots returned from a committee membership of 60: C 67, affirmative 36, negative 0, ballots marked "not voting" 4; C 90, affirmative 35, negative 0, ballots marked "not voting" 5.

[2] 1942 Book of A.S.T.M. Standards, Part II.

[3] 1944 Book of A.S.T.M. Standards, Part II.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. Revision of Tentative Standard			
Spec. for Glazed Building Units (C 126 – 39 T)	27	0	2
II. Adoption of Tentative Standard as Standard			
Spec. for Building Brick (Made from Clay or Shale) (C 62 – 41 T)	27	0	2
III. Adoption as Standard of Tentative Revisions of Standards			
Spec. for Hollow Load-Bearing Concrete Masonry Units (C 90 – 39; ASA A79.1-1942)	27	0	2
Methods of Sampling and Testing Brick (C 67 – 41; A82.1-1942), adoption of C 67 – 42 T, as revised	27	0	2
IV. Reaffirmation of Standards			
Spec. for Concrete Building Brick (C 55 – 37)	33	0	2
Spec. for Sand-Lime Building Brick (C 73 – 39)	33	0	2
Spec. for Structural Clay Floor Tile (C 57 – 39)	33	0	2
Spec. for Hollow Non-Load-Bearing Concrete Masonry Units (C 129 – 39)	33	0	2
Spec. for Concrete Masonry Units for Construction of Catch Basins and Manholes (C 139 – 39)	33	0	2
Sampling and Testing Structural Clay Tile (C 112 – 36)	33	0	2
Def. of Terms Relating to Structural Clay Tile (C 43 – 36)	33	0	2
Sampling and Testing Concrete Masonry Units (C 140 – 39)	33	0	2

IV. Reaffirmation of Standards

It is recommended that the specifications, methods of test, and definitions listed under Item IV of Table I be continued as standard without revision.

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 51 members; with the results shown in Table I.

Activities of Subcommittees

Subcommittee III on Concrete Units (W. G. Kaiser, chairman).—A report by R. E. Copeland, Portland Cement Association, on an investigation of methods of preparing header (recessed) units for compression tests was made available to members of the subcommittee. The information given in the report indicates that the current methods can be improved, but no revisions are proposed at present.

Subcommittee VIII on Structural Clay Tile (H. C. Plummer, chairman).—The drafting of requirements for facing tile, while still unfinished, is proceeding much more rapidly than heretofore. In addition, new studies are under way to develop appropriate requirements for the various grades and types of tile which will enable purchasers to obtain products that have the desired characteristics for each of the most common uses.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Honorary Chairman, J. R. Lawson.
Chairman, D. E. Parsons.
First Vice-Chairman, Theodore I. Coe.
Second Vice-Chairman, W. G. Kaiser.
Secretary, J. W. Whittemore.

This report has been submitted to letter ballot of the committee which consists of 51 members; 32 members returned their ballots, all of whom voted affirmatively.

Respectfully submitted on behalf of the committee,

D. E. Parsons,
Chairman.

J. W. Whittemore,
Secretary.

REPORT OF COMMITTEE C-16

ON

THERMAL INSULATING MATERIALS

Committee C-16 on Thermal Insulating Materials and several of its subcommittees held meetings on only one occasion during the past year, on February 28, 1944, in Cincinnati, Ohio, during the Spring Group Meetings of the Society. It was planned to hold the regular biennial election of officers during this meeting but the absence of a quorum made this impossible. The report of the nominating committee was read and the slate of nominees was later approved by letter ballot vote in the committee as follows: From a membership of 52, 50 members returned their ballots, unanimously electing the following officers for the ensuing term of two years:

Honorary Chairman, J. H. Walker.
Chairman, E. T. Cope.
Vice-Chairman, R. H. Jebens.
Secretary, Ray Thomas.
Advisory Committee, P. D. Close, R. H. Heilman, and B. A. Hollenbeck.

I. New Tentative Standards

The committee recommends that the following specifications be accepted for publication as tentative. These specifications were formerly Emergency Standards as indicated in which certain minor revisions have been incorporated.[1]

Tentative Specifications for:

85 per cent Magnesia Thermal Insulating Cement [formerly issued as Emergency Standard ES - 8],
Asbestos Thermal Insulating Cement [formerly issued as Emergency Standard ES-9],
Mineral Wool Thermal Insulating Cement [formerly issued as Emergency Standard ES - 10],
Expanded or Exfoliated Vermiculite Thermal Insulating Cement [formerly issued as Emergency Standard ES - 11], and
Diatomaceous Silica Thermal Insulating Cement, [formerly issued as Emergency Standards ES - 12 and ES - 13].

II. Adoption of Tentative Standards as Standard

The committee recommends that the definitions and methods of test listed in Item II of Table I be approved without change for reference to letter ballot of the Society for adoption as standard.

III. Tentative Standards Continued as Tentative

The committee recommends that the following tentative standards which have remained in the tentative status for two years or more without revision be continued as tentative:

Tentative Methods of Test for:

Compressive Strength and Flexural Strength of Preformed Block Type Thermal Insulating Materials (C 165 - 41 T),
Covering Capacity and Volume Change Upon Drying of Thermal Insulating Cement (C 166 - 41 T), and
Thermal Conductivity of Materials by Means of the Guarded Hot Plate (C 177 - 42 T).

IV. Emergency Standards

As mentioned earlier in this report, five of the emergency specifications under the jurisdiction of Committee C-16 are being recommended for publication as tentative at this Annual Meeting.

---

[1] These specifications were accepted as tentative by the Society and appear in the 1944 Book of A.S.T.M. Standards, Part II.

The committee recommends that the Emergency Specifications for Diatomaceous Silica Thermal Insulating Cement, for Use from 600 to 1200 F. (ES - 12) be withdrawn.

The remaining emergency specifications are recommended for continuation in their present status without revision, as follows:

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. NEW TENTATIVE STANDARDS			
Spec. for 85 per cent Magnesia Thermal Insulating Cement	43	2	4
Spec. for Asbestos Thermal Insulating Cement	41	4	4
Spec. for Mineral Wool Thermal Insulating Cement	41	4	4
Spec. for Expanded or Exfoliated Vermiculite Thermal Insulating Cement	39	4	6
Spec. for Diatomaceous Silica Thermal Insulating Cement.	40	4	5
II. ADOPTION OF TENTATIVE STANDARDS AS STANDARD			
Sampling and Mixing Thermal Insulating Cement (C 163 - 41 T)	42	2	5
Test for Bulk Density of Thermal Insulating Cement (C 164 - 41 T)	40	4	5
Test for Thickness and Density of Blanket Type Thermal Insulating Materials (C 167 - 41 T)[a]	38	7	4
Def. of Terms Relating to Thermal Insulating Materials (C 168 - 41 T)	42	3	4

[a] The classified vote on the proposed adoption as standard of the Tentative Methods of Test for Thickness and Density of Blanket Type Thermal Insulating Materials (C 167 - 41 T) was as follows: Affirmative: 00 producers, 00 consumers, 00 general interests; negative: 4 producers, 1 consumer, 2 general interests.

Emergency Specifications for:

Blanket Thermal Insulation for Building Purposes (ES - 14),

Blanket Thermal Insulation for Industrial Purposes (ES - 15),

Blanket Thermal Insulation for Refrigeration Purposes (ES - 16),

Preformed Pipe Covering Thermal Insulation (ES - 17),

Preformed Block Thermal Insulation (ES - 18), and

Structural Insulating Board Thermal Insulation (ES - 19).

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 52 voting members, 49 members returned their ballots, with the results shown in Table I.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Physical Properties of Preformed Block Insulation, Including Pipe Covering (R. H. Jebens, chairman).—The subcommittee has under consideration revisions in the Tentative Methods of Test for Compressive Strength and Flexural Strength of Preformed Block Type Thermal Insulating Materials (C 165 - 41 T) to make them agreeable to all concerned prior to recommending their adoption as standard.

Subcommittee II on Physical Properties of Insulating Board Made from Both Mineral and Vegetable Materials (P. D. Close, chairman).—This subcommittee has as its assignment the preparation of specifications and test procedures applying to insulating board. This work entails the determination of the significant physical properties, the selection or creation of test procedures that will fairly measure these properties, and the placing of reasonable numerical limits on the values of the significant properties.

Subcommittee III on Physical Properties of Thermal Insulating Cement (H. W. Greider, chairman).—During the past year this subcommittee has revised the Emergency Specifications for Thermal Insulating Cement and is now recommending them as revised for publication as tentative.

Subcommittee IV on Physical Properties of Blanket and Semirigid Insulation Made from Both Mineral and Vegetable Materials (R. E. Cryor, chairman).—This subcommittee has two problems under consideration: (*1*) to decide what properties of blanket and semirigid types of insulation are the most important, and (*2*) how to measure them quantitatively. Some progress has been made. It seems to be necessary first to study all the suggested properties, second to discard those obviously unimportant, and third to decide on test procedures that will fairly evaluate the properties selected.

Subcommittee V on Physical Properties of Loose-Fill Thermal Insulation Made from Both Mineral and Vegetable Materials (G. J. Christner, chairman).—The work being undertaken by this subcommittee is in a field in which little quantitative work has been done. In consequence the desirable characteristics of loose-fill insulations must first be selected; then test procedures to measure these qualities must be devised. This work proceeds slowly but some progress has been made.

Subcommittee VI, the A.S.T.M. Group of the Joint Committee on Thermal Conductivity of All Forms of Insulation (F. C. Houghten, chairman).—No meeting of this subcommittee or of the joint committee was held during the past year because the chairman, Commander Houghten, U.S.N.R., has been so occupied with work in the U. S. Navy that at times took him outside of the United States and accordingly the work of Subcommittee VI has been held in abeyance.

Subcommittee VII on Measurement of Thermal Properties Other than Thermal Conductivity of Thermal Insulating Materials (C. B. Bradley, chairman).—This subcommittee has as its objective the standardization of methods of test for specific heat, coefficient of linear expansion, and of other thermal properties of heat insulating materials.

Subcommittee VIII on Studies of Dimensional Standards of Preformed Block Insulation (Ray Thomas, chairman).—This group has completed a study of the present great diversity of thicknesses now listed in producers' catalogs and has formulated a simplified list of standard thicknesses that greatly reduces the number of items necessary to be carried in stock. This new schedule has been submitted to various manufacturers for their consideration.

Subcommittee IX on Studies of Vapor Barriers Applied to Thermal Insulation Used Especially in the Air Conditioning and Refrigeration Fields (R. H. Heilman, chairman).—The program of this subcommittee was such that it early became apparent that the American Society of Heating and Ventilating Engineers and the American Society of Refrigerating Engineers should be greatly interested in it. In consequence these two societies were invited to participate in this standardization work. As a result, both societies have joined with Subcommittee IX in the formation of a Joint Committee on Vapor Barrier Studies. Paul McDermott of Johns-Manville Research Laboratories represents A.S.R.E. on this joint committee and Lieut. Commander E. R. Queer, U.S.N.R., represents A.S.H.V.E.

Through the efforts of Lieut. Commander Queer, the Office of Production, Research, and Development of the War Production Board became interested in the work of this joint committee. A definite program of work was prepared and the O.P.R.D. is now sponsoring work at the University of Michigan in which the program outlined is being carried out under the direction of the Joint Committee on Vapor Barrier Studies. This work is progressing in a satisfactory manner.

Subcommittee X on Editorial Functions (B. A. Hollenbeck, chairman).—This subcommittee has, as in the previous year, conducted its work by correspondence.

This report has been submitted to letter ballot of the committee which consists of 52 members; 47 members returned their ballots, of whom 45 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the committee,

E. T. COPE,
Chairman.

RAY THOMAS,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting Committee C-16 presented to the Society through Committee E-10 on Standards the following recommendations:

Revision of Tentative Specifications for:

Expanded or Exfoliated Vermiculite Thermal Insulating Cement (C 196 - 44 T), and

Withdrawal of Emergency Specifications for:

85 Per Cent Magnesia Thermal Insulating Cement (ES - 8),
Long-Fiber Asbestos Thermal Insulating Cement (ES - 9),
Mineral Wool Thermal Insulating Cement (ES - 10),
Expanded or Exfoliated Mica Thermal Insulating Cement (ES - 11),
Diatomaceous Silica Thermal Insulating Cement, for Use from 600 to 1200 F. (ES - 12), and Diatomaceous Silica Thermal Insulating Cement, for Use from 1200 to 1900 F. (ES - 13),

The six Emergency Specifications withdrawn were replaced by five new tentative specifications accepted by the Society at the Annual Meeting and issued under the A.S.T.M. designations C 193, C 194, C 195, C 196 and C 197, respectively, as set forth in the annual report.

These recommendations were accepted by Committee E-10 on August 28, 1944. The revised and new tentative specifications appear in the 1944 Book of A.S.T.M. Standards, Part II.

REPORT OF COMMITTEE D-1 ON PAINT, VARNISH, LACQUER, AND RELATED PRODUCTS

Committee D-1 on Paint, Varnish, Lacquer, and Related Products held two meetings during the year: on June 30, 1943, in Pittsburgh, Pa., during the Annual Meeting of the Society, and on February 29, 1944, during the Spring Group Meetings.

At the June meeting, Committee D-1 arranged for the presentation of a paper by Lt. C. M. Mottley, U.S.N.R., on "Statistical Procedure for Testing New Paints," and a paper by Howard R. Moore, Philadelphia Navy Yard Testing Laboratory, on "Comparison of Various Methods for Determining the Drying Rates of Varnish Films."[1]

During the past year Subcommittee XXVII on Interior Flat Paint has been discontinued.

H. E. Smith has been appointed representative of Committee D-1 on Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys, with H. A. Nelson as alternate.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, W. T. Pearce.
Vice-Chairman, E. W. Fasig.
Secretary, C. H. Rose.

Subsequent to the Annual Meeting, Committee D-1 presented to the Society through Committee E-10 on Standards the following recommendations:

New Tentative Specifications for:

Methyl Ethyl Ketone (D 740 - 43 T),
Red and Brown Iron Oxide Pigments. (D 84 - 43 T), superseding Standard Specifications D 84 - 41, and
Orange Shellac and Other Lacs (D 237 - 43 T), superseding Standard Specifications D 237 - 41.

These recommendations were accepted[2] by Committee E-10 on August 30, 1943, and the new tentative standards appear in the 1943 Supplement to Book of A.S.T.M. Standards, Part II.

On January 31, 1944, Committee E-10 accepted a new Emergency Method of Test for Changes in Protective Properties of Organic Coatings on Steel Surfaces When Subjected to Immersion (ES - 35), which is available as a separate reprint.

Recommendations Affecting Standards

Of the one adviser and thirteen subcommittees each furnished reports of progress and six submitted detailed reports affecting standards as a result of which the committee is submitting eleven new tentative standards, revision of two tentative standards, revision of three standards for immediate adoption, and is recommending the adoption as standard of two tentative standards as revised and of eight tentative standards without revision, and the adoption as standard of one tentative revision of a

---

[1] ASTM Bulletin, No. 124, October, 1943, p. 19.

[2] In submitting these recommendations to Committee E-10 on Standards, Committee D-1 reported the following results of the letter ballot vote of a total of 101 ballots returned from a membership of 222: D 740, affirmative 59, negative 0, ballots marked "not voting" 42; D 84 and D 237, affirmative 60, negative 1, ballots marked "not voting" 40.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. NEW TENTATIVE STANDARDS			
Spec. for Raw Umber	69	0	51
Spec. for Burnt Umber	69	0	51
Spec. for Raw Sienna	69	0	51
Spec. for Burnt Sienna	69	0	51
Spec. for Venetian Red	72	0	48
Spec. for Yellow Iron Oxide Hydrated	70	0	50
Spec. for Black Synthetic Iron Oxide	70	0	50
Spec. for Isopropyl Alcohol	64	0	56
Test for Daylight 45 Degree, 0 Degree Apparent Reflectance of Paint Finishes	67	0	53
Test for Water in Lacquer, Solvents, and Diluents	67	0	53
Evaluating the Degree of Flaking (Scaling) of Exterior Paints of the Linseed Oil Type	74	0	46
II. REVISION OF TENTATIVE STANDARDS			
Def. of Terms Relating to Paint, Varnish, Lacquer, and Related Products (D 16 – 42 T)	97	0	23
Test for Specular Gloss of Paint Finishes (D 523 – 41 T)	84	0	36
III. REVISION OF STANDARD, IMMEDIATE ADOPTION			
Chemical Analysis of Dry Red Lead (D 49 – 37; ASA K16.1-1937)	71	0	49
Sampling and Testing Lacquer Solvents and Diluents (D 268 – 42)	68	2	50
Spec. for Wood to Be Used as Panels in Weathering Tests of Paints and Varnishes (D 358 – 38)	77	1	42
IV. ADOPTION OF TENTATIVE STANDARDS AS STANDARD			
Spec. for Basic Sulfate White Lead (D 82 – 42 T), as revised	69	0	51
Spec. for Isopropyl Acetate (D 657 – 42 T)	63	0	57
Sampling and Testing Aluminum Powder and Paste (D 480 – 42 T)	72	0	48
Test for Consistency of Exterior House Paints and Enamel-Type Paints (D 562 – 42 T)	73	1	46
Evaluating Degree of Chalking of Exterior Paints of the Linseed-Oil Type (D 659 – 42 T)	78	0	42
Evaluating Degree of Checking of Exterior Paints of the Linseed-Oil Type (D 660 – 42 T)	77	0	43
Evaluating Degree of Cracking of Exterior Paints of the Linseed-Oil Type (D 661 – 42 T)	77	0	43
Evaluating Degree of Erosion of Exterior Paints of the Linseed-Oil Type (D 662 – 42 T)	78	0	42
Test for Abrasion Resistance of Organic Coatings with the Air Blast Abrasion Tester (D 658 – 42 T)	70	1	49
Test for Spectral Characteristics and Color of Objects and Materials (D 307 – 42 T), as revised	59	0	61
V. ADOPTION AS STANDARD OF TENTATIVE REVISION OF STANDARD			
Spec. for Zinc Oxide (D 79 – 41; ASA K22-1941)	72	0	48

standard. The standards affected are listed in Table I and the recommendations are explained in the reports of the subcommittees directly responsible for them.

These recommendations have been submitted to letter ballot of the committee which consists of 237 voting members, with the results shown in Table I.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee II on Drying Oils (Francis Scofield, chairman) recommends that the Tentative Specifications for Oiticica Oil (Permanently Liquid) (D 601 – 41 T) be continued as tentative without revision because very little oiticica oil has been available during the past year and therefore there has not been adequate opportunity to try the tentative specifications.

The subcommittee is investigating methods of test for dehydrated castor oil, bodied linseed oil, and treated oils. It is also developing a method of making varnish, which will be useful as a method for evaluating drying oils, and a method for determining the drying time of oils.

Subcommittee IV on Traffic Paints (Anthony Skett, chairman) is progressing on the selection of photographs to show the various stages of erosion of traffic paint films and also photographs for failure by chipping. The subcommittee has completed work on the development of laboratory tests to predict the road service qualities of traffic paints. It is conducting cooperative tests on hiding power and on the day and night visibilities of traffic paints. A study of the bleeding properties of traffic paints is being conducted. Preliminary work has indicated that tar paper may be advantageously used for the laboratory evaluation of bleeding of traffic paints.

Subcommittee V on Volatile Solvents for Organic Protective Coatings (E. M.

Toby, Jr., chairman) has established the following groups:

Group 1 on Solvency Definitions and Procedures for the Determination of Hydrocarbon Solvency,
Group 3 on Volatility,
Group 4 on Turpentine and Related Terpene Hydrocarbons, and
Group 5 on New Specifications.

Group 1 is conducting cooperative work on methods for evaluating solvency; Group 3 is now working on the determination of evaporation rates; and Group 5 is considering specifications for heavy mineral spirits.

Subcommittee VI on Definitions (C. H. Rose, chairman) recommends that the Tentative Definitions of Terms Relating to Paint, Varnish, Lacquer, and Related Products (D 16 – 42 T) be revised as appended hereto.[3] The changes involve the addition of new definitions for bleeding, pigment volume, and bulking value, revisions in the definitions for drier, vehicle, spreading rate, and baking finish, and the omission of four definitions covering, respectively, United States and Imperial gallon, fineness, and specific gravity.

Subcommittee VII on Accelerated Tests for Protective Coatings (H. A. Nelson, chairman) recommends for publication as tentative a Method of Test for Evaluating the Degree of Flaking (Scaling) of Exterior Paints of the Linseed Oil Type.[4]

The following revision is recommended for immediate adoption in the Standard Specifications for Wood to be Used as Panels in Weathering Tests of Paints and Varnishes (D 358 – 38):

Section 1.—Add the following minimum thickness requirements:

> In order to minimize warping during exposure, the following minimum thickness shall apply depending on the width or across-the-grain dimension:[a]

Panel Width, in.	Minimum Thickness, in.		
	Cedar	White Pine	Yellow Pine
3 and under	3/8	7/16	7/16
Over 3 to 6 incl.	7/16	3/4	3/4
Over 6	3/4	7/8	7/8

[a] These limitations do not apply to panels made of clapboard or siding of commercial types which shall be used as regularly marketed.

The subcommittee recommends that the following tentative methods be adopted as standard without change:

Tentative Methods of:

Evaluating Degree of Chalking of Exterior Paints of the Linseed-Oil Type (D 659 – 42 T),
Evaluating Degree of Checking of Exterior Paints of the Linseed-Oil Type (D 660 – 42 T),
Evaluating Degree of Cracking of Exterior Paints of the Linseed-Oil Type (D 661 – 42 T), and
Evaluating Degree of Erosion of Exterior Paints of the Linseed-Oil Type (D 662 – 42 T).

The subcommittee recommends, in view of the contemplated changes, that the Tentative Method for Preparation of Steel Panels for Exposure Tests of Enamels for Exterior Service (D 609 – 41 T) be continued as tentative.

The subcommittee has continued the study of steel panels and methods of cleaning. It has cooperated with the Quartermaster General's Office on questions concerning the further standardization of a salt spray test method which may result in the revision of the Emergency Method for Conducting Salt Spray Tests on Organic Protective Coatings (ES – 3). The subcommittee is also seeking sources for the correlation of data on accelerated weathering tests and exposure tests.

Subcommittee VIII on Methods of Analysis of Paint Materials (E. F. Hickson, chairman) recommends the adoption as standard of the Tentative Methods of Sampling and Testing Aluminum Powder and Paste (D 480 – 42 T) and the Tentative Method of Test for Consistency of Exterior House Paints and Enamel-Type Paints (D 562 – 42 T).

---

[3] 1944 Book of A.S.T.M. Standards, Part II.

[4] This method was accepted as tentative by the Society and appears in the 1944 Book of A.S.T.M. Standards, Part II.

The subcommittee recommends for immediate adoption the following revision of the Standard Methods of Chemical Analysis of Dry Red Lead (D 49 – 37):

Section 6.—Add the following to the Note at the front of this section: "or substances such as metallic lead, which reduce PbO_2 to PbO without the liberation of iodine." The subcommittee believes that this caution is necessary in view of the fact that by the methods investigated it was definitely not possible to make an accurate determination of red lead in the presence of metallic lead.

Subcommittee IX on Varnish (W. T. Pearce, chairman) is studying methods for measuring the drying of varnishes and alkyd resin finishes. It is also investigating improvements in the methods for testing alkyd resin solutions. A survey is being made of methods of testing resins used in varnish-type finishes.

Subcommittee XIII on Shellac (W. H. Gardner, chairman) recommends that the Tentative Method of Test for Color of Orange Shellac (D 29 – 41 T) be continued as tentative because consideration is being given to recommending certain changes in this method.

Subcommittee XV on Specifications for Pigments Dry and In Oil When Marketed in That Form (C. L. Crockett, chairman) recommends for publication as tentative seven specifications[5] covering the following types of pigments: Raw Umber, Burnt Umber, Raw Sienna, Burnt Sienna, Venetian Red, Yellow Iron Oxide Hydrated, and, Black Synthetic Iron Oxide.

The subcommittee recommends the adoption as standard of the tentative revision[6] of the Standard Specifications for Zinc Oxide (D 79 – 41).

The subcommittee recommends the adoption as standard of the Tentative Specifications for Basic Sulfate White Lead (D 82 – 42 T), revised as follows:

Section 2 (a).—Change the minimum requirement for lead oxide from "11.0" to read "15.0" per cent.

The subcommittee is reviewing all the specifications for pigments looking toward bringing them up to date and in line with the materials offered to the trade.

Subcommittee XVIII on Physical Properties of Materials (M. Rea Paul, chairman) recommends the adoption as standard of the Tentative Method of Test for Spectral Characteristics and Color of Objects and Materials (D 307 – 42 T), revised as follows:

Section 2 (c).—Change to read as follows by the addition of the italicized words and the omission of those in brackets: "Spectral Irradiance, E_λ.—The *density of* radiant flux incident on *an element of* surface [per unit area] per unit wave length."

The subcommittee recommends a revision of the Tentative Method of Test for Specular Gloss of Paint Finishes (D 523 – 41 T). This consists of a procedure for the comparison of the gloss of surfaces of low and medium gloss for all surfaces in any group have approximately the same diffuse reflectance. The changes are as follows:

Section 1.—In the first sentence, change "two procedures" to read "three procedures" and add the following paragraph at the end of this section:

> *Procedure C* may be used for the routine comparison of the gloss of surfaces of low and medium gloss where all surfaces in any group have approximately the same diffuse reflectance.

Section 2.—Change footnote 4 to read as follows:

---

[5] These specifications were accepted as tentative by the Society and appear in the 1944 Book of A.S.T.M. Standards, Part II.

[6] 1943 Supplement to Book of A.S.T.M. Standards, Part II.

[4] Interchange of source and receptor is permissible. It should be noted that procedure C does not measure the quantity here defined because it does not provide for subtracting the brightness of the sample when viewed normally from the brightness when viewed in the direction of specular reflection. As noted above, however, procedure C has been designed for the rapid gloss comparison of surfaces of approximately the same diffuse reflectance.

Section 3 (b).—Add the following to the last sentence: "except in instruments designed only for measurements according to procedure C."

Section 4.—Add a new Paragraph (*c*) to read as follows:

(*c*) *Procedure C.*—For measurements of specular gloss according to procedure C, the 60 deg. illuminating and −60 deg. viewing conditions specified for procedure A shall be used. Values of specular gloss according to procedure C are therefore always higher than values for the same specimens according to procedure A by the amounts of the diffuse corrections required by procedure A.

Section 6 (b).—Change the phrase "For measurement in accordance with procedure A" to read "For measurement in accordance with procedures A or C."

The subcommittee recommends for publication as tentative the Method of Test for Daylight 45 Degree, 0 Degree, Apparent Reflectance of Paint Finishes.[4]

The subcommittee has initiated work on the development of a method for measuring infrared reflectance.

Subcommittee XXV on Cellulosic Coatings and Related Materials (R. M. Carter, chairman) recommends that the Tentative Specifications for Isopropyl Acetate (D 657 – 42 T) and the Tentative Method of Test for Abrasion Resistance of Organic Coatings with the Air Blast Abrasion Tester (D 658 – 42 T) be adopted as standard.

The subcommittee recommends for immediate adoption the following revision of the Standard Methods of Sampling and Testing Lacquer Solvents and Diluents (D 268 – 42):

Section 11.—Add the following note at the end of this section: "*Note.*—Any suitable aqueous alkali may be used in place of aqueous KOH."

This action will permit the use of ordinary aqueous NaOH.

Section 21.—In the first sentence, change "100-g." to read "25-g." and "16 hr." to read "3 hr."

This change makes a speedier determination possible.

The subcommittee recommends for publication as tentative Specifications for Isopropyl Alcohol[5] and a Method of Test for Water in Lacquer, Solvents, and Diluents.[4]

On June 30, 1943, Committee D-1 approved changing the name of this subcommittee to Subcommittee on Cellulosic Coatings and Related Materials. A new working group on noncellulosic coatings has been established within the subcommittee. This group will study methods of test and specifications for materials other than cellulosic of a resin, plastic or polymeric nature, which are now being used to prepare protective coatings.

Subcommittee XXIX on Painting of Structural Iron and Steel (A. J. Eickhoff, chairman) has been studying the effect of chemical pretreatment of rusted, sandblasted, and semirusted panels. Treated and painted panels which had been on exposure have been retreated and repainted with materials which had been used in the previous test. The object of this work is to study the effect of retreating painted, weathered panels with chemical treatments prior to repainting.

This report has been submitted to letter ballot of the committee which consists of 237 voting members; 120 members returned their ballots, of whom 90 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the committee,

H. E. SMITH,
Chairman.

M. REA PAUL,
Secretary.
C. H. ROSE,
Assistant Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting Committee D-1 presented to the Society through Committee E-10 on Standards the following recommendations:

Revised Tentative Specifications for:

Wood to be Used as Panels in Weather Tests of Paints and Varnishes (D 358 – 44 T), to supersede Standard Specifications D 358 – 44,

Tentative Revision of Standard Specifications for:

Zinc Sulfide Pigments (D 477 – 41),

Withdrawal of Emergency Method for:

Conducting Salt Spray Tests on Organic Protective Coatings (ES – 3), and

New Tentative Methods of:

Sampling and Testing Turpentine (D 233 – 44 T), to supersede Standard Methods D 233 – 36.

The first two recommendations were accepted by Committee E-10 on August 28, 1944, and the tentative specifications and tentative revision appear in the 1944 Book of A.S.T.M. Standards, Part II.

On September 27, 1944, the Standards Committee accepted the recommendation of Committee D-1 that Emergency Method ES – 3 be withdrawn, and on October 30, 1944, accepted proposed Tentative Methods D 233 – 44 T which also appear in the 1944 Book of A.S.T.M. Standards, Part II.

REPORT OF COMMITTEE D-2
ON
PETROLEUM PRODUCTS AND LUBRICANTS

Committee D-2 on Petroleum Products and Lubricants held three regular meetings during the past year (in June at Pittsburgh, Pa., in January at Detroit, Mich., and in March at Cincinnati, Ohio).

During the year Subcommittee XXV on Analysis of Petroleum Products for Hydrocarbon Types organized four new sections on the following subjects: Section A on Determination of Total Olefins and Aromatics by Acid Treatment (S. S. Kurtz, Jr., chairman); Section B on Determination of Olefinic Unsaturation by Chemical Methods (E. T. Scafe, chairman); Section C on Use of Adsorbents in Hydrocarbon Analysis (F. D. Rossini, chairman); and Section D on Refractive Index, Dispersion, and Density (F. D. Tuemmler, chairman).

TABLE I.

Title	A.S.T.M. Designation	ASA Number
NEW AMERICAN STANDARDS		
Test for Carbonizable Substances in Paraffin Wax....	D 612 - 43	Z11.50—1943
Test for Carbonizable Substances in White Mineral Oil (Liquid Petrolatum)...	D 565 - 43	Z11.49—1943
Test for Dropping Point of Lubricating Grease........	D 566 - 42	Z11.51—1943
REVISION OF AMERICAN STANDARDS		
Test for Vapor Pressure of Petroleum Products (Reid Method)..................	D 323 - 43	Z11.44—1943
Viscosity-Temperature Charts for Liquid Petroleum Products.............	D 341 - 43	Z11.39—1943

Section VIII on Aviation Gasoline Specifications of Technical Committee A on Gasoline was discharged as it is impracticable to continue this activity under wartime conditions.

Table I shows the changes in status during the year of American Standards for petroleum products, approved by the American Standards Association on the recommendation of Sectional Committee Z11 on Petroleum Products and Lubricants.

Subcommittee VI on Color (H. M. Hancock, chairman), at the request of the U. S. Army Ordnance Dept., prepared an Emergency Method of Test for Color of U. S. Army Motor Fuel (All-Purpose) by Means of an A.S.T.M. Color Standard which was accepted by Committee E-10 on August 24, 1943, and assigned the designation ES - 32.

Subcommittee VII on Sulfur Determination (H. M. Hancock, chairman) has determined cooperatively the sulfur content of five oils in accordance with the Standard Method of Test for Sulfur in Petroleum Oils by Bomb Method (D 129 - 39). The sulfur in these oils ranged from less than 0.10 to more than 2.5 per cent. The data indicate (see Table II) that the reproducibility as described in the method is not reasonable for oils with very low sulfur content and the subcommittee recommends that Section 6 be revised as described later in this report.

Subcommittee XI on Inorganic Elements in Lubricants (Raymond Haskell, chairman) has developed methods of test for sulfur, chlorine, phosphorus and

TABLE II.—RESULTS OF COOPERATIVE DETERMINATIONS OF SULFUR BY METHOD D 129 – 39.

	Sulfur, per cent									
	Sample A, U.S.P. White Oil, 340 sec., Saybolt Universal Viscosity at 100 F.		Sample B, Coastal Oil, 750 sec., Saybolt Universal Viscosity at 100 F.		Sample C, Topped Crude		Sample D, No. 6 Fuel Oil		Sample E, West Texas Crude Residuum	
	A[a]	B[a]	A	B	A	B	A	B	A	B
Laboratory 1	0.02	0.03	0.61[b]	0.67[b]	1.12	1.13[b]	2.11[b]	1.93[b]	2.77[b]	2.96
	0.03	0.04	0.57	0.57[b]	1.11	1.23[b]	2.10[b]	2.11[b]	2.89	2.97
	0.03	0.05	0.54[b]	0.63	1.06[b]	1.19	1.87[b]	2.16[b]	2.90[b]	2.95
Average	0.03	0.04	0.57	0.62	1.10	1.18	2.03	2.07	2.85	2.96
Laboratory 2	0.05	0.01	0.61	0.54	1.11[b]	1.03	2.10	1.95	2.92	2.78
	0.06	0.02	0.58	0.49[b]	1.17[b]	1.07	2.12	2.02	2.98	2.77
Average	0.06	0.02	0.60	0.52	1.14	1.05	2.11	1.98	2.95	2.78
Laboratory 3	0.04	0.05	0.53	0.53	1.12	1.13	2.14	2.04	2.90	2.91
	0.03	0.04	0.56	0.53	1.13	1.15	2.10	2.06	2.93	2.93
	0.03	0.04	0.54	0.51	1.10	1.11	2.09	2.03	2.91	2.91
Average	0.03	0.04	0.54	0.52	1.12	1.13	2.11	2.04	2.91	2.92
Laboratory 4	0.06	0.03	0.59	0.64[b]	1.14	1.14	2.23[b]	2.16	2.97	2.98
	0.06	0.03	0.59	0.58	1.12	1.13	2.17	2.15	2.97	2.96
	0.05	0.03	0.59	0.59	1.10	1.14	2.14[b]	2.18	2.96	2.97
Average	0.06	0.03	0.59	0.60	1.12	1.14	2.18	2.16	2.97	2.97
Laboratory 5	0.07[b]	0.03	0.51[b]	0.56	1.12	1.05	2.06[b]	2.10	2.80	2.79
	0.04	...	0.53	0.56	1.09	1.05	2.11	2.07	2.77	2.80
	0.05	...	0.59[b]	...	1.13	...	2.12	...	2.82	...
Average	0.05	0.03	0.54	0.56	1.11	1.05	2.10	2.08	2.80	2.80
Laboratory 6	0.07	0.06	0.58	0.57	1.09	1.13	2.14	2.09	2.95	2.87
	0.05	0.06	0.58	0.59	1.07	1.15	2.12	2.07	2.92	3.87
	0.06	...	...	...	...	...	...	...	...	...
Average	0.06	0.06	0.58	0.58	1.08	1.14	2.13	2.08	2.94	2.87
Laboratory 7	0.04	0.03	0.58	0.58	1.13	1.12	2.10[b]	2.15[b]	2.98	2.99
	0.03	0.03	0.57	0.62	1.13	1.13	2.15	2.26[b]	2.96	3.05[b]
	0.04	0.03	0.56	0.60	1.15	1.15	2.21[b]	2.23	2.98	2.98
Average	0.04	0.03	0.57	0.60	1.14	1.13	2.15	2.21	2.97	3.01
Laboratory 8	0.04	0.08	0.56	0.56	1.09	1.13	2.10	2.10	2.78	2.82
	0.04	0.06	0.55	0.56	1.10	1.16	2.13	2.12	2.81	2.87
	0.05	0.07	0.58	0.52[b]	1.12	1.12	2.14	2.04[b]	2.86	2.84
Average	0.04	0.07	0.56	0.55	1.10	1.14	2.12	2.09	2.82	2.84
Grand Average	0.04		0.57		1.12		2.10		2.90	
Average Deviation	0.01		0.02		0.03		0.04		0.06	
Maximum Deviation	0.03		0.05[c]		0.07[d]		0.12[e]		0.12[f]	

[a] The letters **A** and **B** represent different operators in each laboratory.
[b] Exceeds deviations for one operator in proposed revisions.
[c] Three instances where deviation is greater than 0.04 as specified in proposed revision.
[d] Three instances where deviation is greater than 0.05 as specified in proposed revision.
[e] Three instances where deviation is greater than 0.07 as specified in proposed revision.
[f] Five instances where deviation is greater than 0.07 as specified in proposed revision.

metals in lubricating oils which has resulted in the publication of four emergency methods of test and one emergency alternate provision as follows:

Emergency Alternate Provisions in:

Standard Method of Test for Sulfur in Petroleum Oils by Bomb Method (EA – D 129)

Emergency Methods of Test for:

Chlorine in Lubricating Oils by Bomb Method (ES – 36),
Phosphorus in Lubricating Oils (ES – 37),
Lead, Copper, and Iron in Lubricating Oils (ES – 38), and
Metals in Lubricating Oils (ES – 39).

The cooperative data obtained by the use of these methods are presented in Tables III to VI.

TABLE III.—RESULTS OF COOPERATIVE DETERMINATIONS OF SULFUR AND CHLORINE BY EMERGENCY METHODS EA - D 129 AND ES - 36.[a]

Laboratory	Sample S-20		Sample S-21		Sample S-22		Sample S-23	
	Sulfur, per cent	Chlorine, per cent[b]	Sulfur, per cent	Chlorine, per cent[b]	Sulfur, per cent	Chlorine, per cent[b]	Sulfur, per cent	Chlorine, per cent[b]
1	0.50	2.03 V[d]	0.36	0.38 V[d]	2.00	0.41 V	2.00[d]	1.99 V
2	0.51	2.08 V[d]	0.36	0.37 V[d]	1.95	0.36 V	2.08	2.09 V[d]
3	0.55 ...	1.98 V 1.92 G	0.39 ...	0.30 V 0.29 G	1.87[d] ...	0.31 V[d] 0.33 G[d]	2.05 ...	1.90 V 1.88 G[d]
4	0.69[c]	2.05 V[d]	0.58[c]	0.33 V	2.37[c]	0.38 V	2.35[c]	1.91 V
5	0.53	1.95 G	0.41	0.30 G	2.04[d]	0.36 G	2.05	2.30 V[c]
6	0.56	...	0.33[d]	...	2.04[d]	...	2.06	...
7	0.54 ...	1.96 V 1.94 G	0.44[d] ...	0.50 V[c] 0.47 G[c]	1.95 ...	0.46 V[d] 0.44 G[d]	2.06 ...	1.95 V 1.96 G
8	0.53 ...	1.88 V[d] 1.94 G	0.46[d] ...	0.30 V 0.30 G	2.02 ...	0.35 V 0.35 G	2.09 ...	1.90 V 1.95 G
Average	0.53	1.97	0.39	0.32	1.98	0.38	2.06	1.95
Average Deviation	0.016	0.049	0.037	0.029	0.05	0.039	0.019	0.044
Maximum Deviation	0.03	+0.11	+0.07	+0.06	−0.11	+0.08	−0.06	+0.14
Percentage Present	0.54	2.04	0.44	0.31	1.96	0.30	2.00	1.92

[a] All results are averages of two or more individual determinations.
[b] V indicates volumetric determination and G indicates gravimetric determination
[c] Not included in averages.
[d] Outside permissible deviation of the emergency method.

TABLE IV.—RESULTS OF COOPERATIVE DETERMINATIONS OF PHOSPHORUS BY METHOD ES - 37.

	Phosphorus, per cent												
Sample	S-1	S-2	S-3	S-4	S-5	S-6	S-7	S-8	S-9	S-20	S-21	S-22	S-23
Laboratory 1	... ...	... ...	... ...	... ...	... ...	... ...	... ...	... ...	... ...	0.19[a] 0.20[a]	0.12 0.12	0.44 0.44	0.39 0.41
Average	...	...	...	...	...	...	...	...	...	0.195	0.12	0.44	0.40
Laboratory 2	... ...	... ...	... ...	... ...	... ...	... ...	... ...	... ...	... ...	0.194[a] 0.201[a]	0.095[a] 0.118[a]	0.432 0.433	0.392 0.391
Average	...	...	...	...	...	...	...	...	...	0.198	0.106[b]	0.432	0.3915
Laboratory 3	0.001 0.001	0.093 0.094	0.148 0.148	0.034 0.036	0.071 0.072	0.069 0.069	0.202 0.208	0.095 0.100	0.66 0.65	0.197 0.202	0.115 0.119	0.418 0.422	0.396 0.396 0.398 0.404
Average	0.001	0.0935	0.148	0.035	0.0715[b]	0.069	0.205	0.098	0.655	0.200	0.117	0.420	0.396
Laboratory 7	0.002 0.001	0.095 0.091	0.16 0.15	0.043[b] ...	0.09[a] 0.08[a]	0.070 ...	... ...	... ...	... ...	... ...	... ...	... ...	... ...
Average	0.0015	0.093	0.155	...	0.085[b]	...	...	...	...	...	...	...	...
Laboratory 8	... ...	0.090 0.089 0.090	... ...	0.032 0.033 0.033	... ...	0.067 0.067 0.069	... ...	... ...	... ...	... ...	0.113 0.113 0.111	... ...	... ...
Average	...	0.090	...	0.033[b]	...	0.068	...	...	...	...	0.112	...	...
Laboratory 9	...	0.093	...	0.033[b]	...	0.065[b]	...	...	...	...	...	...	...
Grand Average	0.0012	0.092	0.152	0.036	0.078	0.068	...	...	...	0.197	0.114	0.431	0.396
Average Deviation	0.00025	0.0013	0.003	0.0035	0.007	0.0015	...	...	...	0.0017	0.0048	0.007	0.0027
Maximum Deviation	...	−0.0026	...	+0.007	...	−0.003	...	...	...	+0.003	−0.008	−0.0011	+0.004
Percentage Present	0.001	0.090	0.150	...	0.070	0.070	0.201	0.099	0.667	0.199	0.117	0.42	0.407

[a] Outside permissible deviation of the emergency method for one operator and apparatus.
[b] Outside permissible deviation of the emergency method for different operators and apparatus.

	Sample S-7						Sample S-8						Sample S-9					
	Lead, per cent	Iron, per cent		Copper, per cent			Lead, per cent	Iron, per cent		Copper, per cent			Lead, per cent	Iron, per cent		Copper, per cent		
	Wet Ash	Wet Ash	Dry Ash	Wet Ash	Dry Ash		Wet Ash	Wet Ash	Dry Ash	Wet Ash	Dry Ash		Wet Ash	Wet Ash	Dry Ash	Wet Ash	Dry Ash	
Laboratory 3	0.50[a]	0.006	0.009	0.002	0.001	...	0.91[a]	0.094	0.097	0.010	0.009	...	0.51	0.080	0.078	0.010	0.009	...
	0.53	0.007	0.010	0.002	0.001	...	0.92	0.094	0.098	0.011	0.009	...	0.50	0.084	0.078	0.012	..	...
	0.55	0.007	0.010	0.002	...	...	0.96[a]	...	...	...	...	...	...	...	0.082[a]	...	...	...
	0.56[a]	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Average.......	0.54	0.007	0.010	0.002	0.001	...	0.93	0.094	0.098	0.010	0.009	...	0.505	0.082	0.079	0.011	0.009	...
Laboratory 4	0.74[b]	0.011[c]	...	0.003	...	...	1.01[b]	0.101[b,c]	...	0.014	...	...	0.57[b]	0.087[c]	...	0.012	...	...
Laboratory 5	0.61	0.007	...	0.004	...	...	1.03	0.069	...	0.012	...	...	0.572	0.071	...	0.012	...	...
	0.63	0.009	...	0.004	...	...	1.05	0.076	...	0.013	...	...	0.589	0.073	...	0.013	...	...
	...	...	...	0.002	...	...	...	...	...	0.009	...	...	...	...	...	0.007	...	...
	...	...	...	0.002	...	...	...	...	...	0.008	...	...	...	...	...	0.007	...	...
	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	0.007	...	...
Average.......	0.62[b]	0.008	...	0.003	...	...	1.04[b]	0.072[b]	...	0.010	...	...	0.580[b]	0.072	...	0.009	...	...
Laboratory 7	0.52	0.010	0.011	...	...	...	0.96	0.110[a]	0.099	0.005	0.009	0.011[d]	0.420	0.095[a]	0.069[a]	0.005	0.009	0.011[d]
	0.54	0.010	0.010	...	0.001	0.001[d]	0.95	0.100[a]	0.093[a]	0.005	0.010	0.010	0.400	0.100	0.078	0.004	0.009	0.011
	...	...	0.011[c]	...	0.001	0.001	...	...	0.098[c]	...	...	...	...	...	0.091[a c]	...	...	...
	...	...	0.011	...	...	...	...	...	0.098	...	...	...	...	...	0.089[a]	...	...	...
Average.......	0.53	0.010	0.011	...	0.001	0.001	0.96	0.105[b]	0.097	0.005	0.010	0.010	0.410[b]	0.098[b]	0.082	0.004[b]	0.009	0.011
Laboratory 8	0.49	0.006	...	0.003	...	...	0.90	0.089[a]	...	0.011	...	...	0.48	0.056	...	0.010	...	...
	0.48	0.006	...	0.003	...	...	0.89	0.096[a]	...	0.012	...	...	0.47	0.051[a]	...	0.010	...	...
Average.......	0.48[b]	0.006[b]	...	0.003	...	...	0.90[b]	0.092	...	0.012	...	...	0.475	0.054[b]	...	0.010	...	...
Laboratory 10	0.48	0.010[c]	0.011[c]	0.019[a]	0.001	0.001[d]	0.97[a]	0.089[c]	0.097[a c]	0.022[a]	...	0.010[d]	0.447	0.081[a c]	0.077[c]	0.016[a]	0.005	0.010[d]
	0.50	...	0.011	0.012	0.001	0.001	0.91[a]	0.089[c]	0.092[a]	0.017[a]	...	0.010	0.464	0.074[a]	...	0.013	0.005	0.010
	...	...	0.012	0.003[a d]	0.002	0.001	...	0.090[c]	0.106[a]	0.013[d]	...	0.010	...	...	0.084	0.011[c]	0.004	0.010
	...	...	0.010	...	...	0.001	...	...	0.107[a]	0.011	...	0.010	...	...	0.084	0.012	0.004	0.010
Average.......	0.49[b]	0.010	0.011	0.012[b]	0.001	0.001	0.94	0.089	0.100	0.016	...	0.010	0.455[b]	0.078	0.082	0.013	0.004[b]	0.010
Laboratory 11	0.37[a]	0.011	...	0.002	...	...	0.87	0.097	...	0.010	...	...	0.41[a]	0.098	...	0.010	...	...
	0.41[a]	0.012	...	0.001	...	...	0.88	0.096	...	0.010	...	...	0.45[a]	0.102[a]	...	0.010	...	...
	...	0.010	...	0.001	...	...	...	0.105[a]	...	0.010	...	...	...	0.095[a]	...	0.010	...	...
	...	0.010	...	0.001	...	...	...	0.095[a]	...	0.010	...	...	...	0.102[a]	...	0.009	...	...
Average.......	0.39[b]	0.011	...	0.001[b]	...	...	0.88[b]	0.098	...	0.010	...	...	0.43[b]	0.099[b]	...	0.010	...	...
Grand Avg........	0,54	0.009	0.011	0.004	0.001	0.001	0.95	0.093	0.098	0.011	0.009	0.010	0.489	0.081	0.081	0.010	0.007	0.010
Avg. Deviation...	0.08	0.0017	0.0003	0.003	0.000	0.000	0.04	0.007	0.001	0.003	...	...	0.053	0.012	0.001	0.002	0.002	...
Max. Deviation...	+0.20	−0.003	−0.001	+0.008	0.000	0.000	+0.009	−0.021	+0.002	−0.006	...	...	+0.091	−0.027	−0.002	−0.006	−0.003	...
% Present........	0.542	0.010	0.010	0.001	0.001	0.001	1.001	0.100	0.100	0.011	0.011	0.011	0.502	0.088	0.088	0.011	0.011	0.011

---

[a] Outside permissible deviation of the emergency method for one operator and apparatus.
[b] Outside permissible deviation of the emergency method for different operators and apparatus.
[c] Determined by measuring KSCN color of the iron.
[d] Determined by extracting an aqueous solution of the copper complex with $CHCl_3$ and measuring color of copper complex in $CHCl_3$.

TABLE VI.—RESULTS OF COOPERATIVE DETERMINATIONS OF BARIUM, ALUMINUM, CALCIUM, MAGNESIUM, ZINC, TIN, AND SILICON BY EMERGENCY METHOD ES - 39.

	Sample S-8			Sample S-9						
	Barium, per cent	Aluminum, per cent	Calcium, per cent	Barium, per cent	Aluminum, per cent	Calcium, per cent	Magnesium, per cent	Zinc, per cent	Tin, per cent	Silicon, per cent
Laboratory 3	0.262	0.068	0.097	0.288	0.105	0.195	0.189	0.556	0.232	0.055
	0.281	0.070	...	0.285	0.104	0.197	0.156	0.531	0.216	0.060
	...	...	...	...	...	0.198	0.204	0.475	0.231	0.019
	...	...	...	...	...	0.201	0.201	0.478	0.216	0.028
Average	0.272	0.069	0.097	0.286	0.104	0.198	0.188	0.510	0.224	0.040
Laboratory 4	0.260	0.050	0.125	0.280	0.030	0.206	0.181	0.360	...	...
Laboratory 5	0.276	0.033	0.092	...	...	...	...	...	...	...
	0.280	0.037	0.093	0.293	0.039	0.194	0.193	0.494	0.240	0.038
	...	...	...	0.279	0.051	0.193	0.196	0.465	0.238	0.032
	...	...	...	0.286	0.065	...	...	0.301	0.235	0.035
Average	0.278	0.035	0.092	0.286	0.052	0.194	0.194	0.420	0.238	0.035
Laboratory 8	0.24	0.030	0.095	...	0.042	0.20	0.21	0.82	0.24	0.02
	0.21	0.050	0.076	...	0.052	0.20	0.21	0.75	0.24	0.03
	0.22	0.050	0.086	...	...	...	...	...	...	...
Average	0.223	0.043	0.086	...	0.047	0.20	0.21	0.78	0.24	0.025
Laboratory 10	0.277	0.067	0.093	0.292	0.064	0.203	0.202	0.46	0.22	0.13
	0.282	0.074	...	0.294	0.075	0.208	0.207	0.536	0.24	0.11
	...	...	...	...	0.070	0.205	0.192	0.589	0.22	0.051
	...	...	...	...	0.065	...	...	...	...	0.062
Average	0.280	0.070	0.093	0.293	0.068	0.205	0.200	0.528	0.227	0.088
Grand Average	0.263	0.053	0.099	0.286	0.060	0.201	0.195	0.520	0.232	0.047
Average Deviation	0.017	0.013	0.011	0.003	0.021	0.004	0.010	0.108	0.007	0.020
Maximum Deviation	−0.040	−0.018	+0.026	+0.007	+0.044	−0.007	+0.015	+0.26	+0.008	+0.041
Percentage Present	0.297	0.069	0.100	0.297	0.075	0.198	0.197	0.494	0.247	0.030

TABLE VII.—EFFECT OF BACK TITRATION ON ACID NUMBER BY METHOD D 663.

Laboratory	No Back Titration			Back Titration (After 50 per cent Overrun of KOH)			
			Average				Average
SAMPLE S1 - 43							
1	0.87	0.91	0.89	1.14	1.17	...	1.16
2	0.55	0.85	0.70	1.31	0.93	...	1.12
3	1.13	1.13	1.13	1.41	1.47	...	1.44
4	1.15	1.12	1.14	1.79	1.62	1.80	1.74
5	1.03	1.02	1.03	1.45	1.48	...	1.47
6	0.74	0.71	0.73	1.40	1.45	...	1.43
7	1.10	1.12	1.11	1.43	1.38	...	1.41
8	...	...	0.92	...	...	...	1.15
Average	...	...	0.96	...	...	...	1.37
Average Deviation	...	...	0.15	...	...	...	0.17
Maximum Deviation	...	...	−0.26	...	..	...	+0.37
SAMPLE S2 - 43							
1	0.89	0.86	0.88	1.17	1.27	...	1.22
2	0.99	0.90	0.95	1.03	0.84	...	0.94
3	1.24	1.30	1.27	1.64	1.75	...	1.70
4	1.47	1.44	...	1.97	2.02	...	2.00
	1.44	...	1.45	...	...	...	...
5	0.98	1.05	1.02	1.28	1.63	1.49	1.47
6	0.80	0.81	0.81	1.60	1.58	...	1.59
7	1.20	1.30	1.25	1.61	1.53	...	1.57
Average	...	...	1.09	...	...	...	1.50
Average Deviation	...	...	0.20	...	...	...	0.25
Maximum Deviation	...	...	+0.36	...	...	...	−0.56

Laboratory	No Back Titration			Back Titration (After 50 per cent Overrun of KOH)		
			Average			Average
SAMPLE S3 - 43						
1	0.82	0.82	0.82	0.90	0.95	0.93
2	0.97	1.06	1.02	0.81	1.02	0.92
3	1.07	1.07	1.07	1.07	1.13	1.10
4	0.95	0.96	0.96	1.08	1.09	1.09
5	0.88	0.85	0.87	0.95	0.98	0.96
6	0.65	0.65	0.65	1.27	1.27	1.27
7	0.92	0.94	0.93	1.02	0.97	1.00
Average	...	...	0.90	...	...	1.04
Average Deviation	...	...	0.10	...	...	0.10
Maximum Deviation	...	...	−0.25	...	...	+0.23
SAMPLE S4 - 43						
1	0.18	0.15	0.17	0.17	0.15	0.16
2	0.16	...	0.16	0.21	...	0.21
3	0.34	0.28	0.31	0.34	0.28	0.31
4	0.21	0.27	...	0.38	0.39	0.39
	0.27	...	0.25	...	...	...
5	0.23	0.25	0.24	0.28	0.25	0.27
6	0.20	0.20	0.20	0.47	0.44	0.46
7	0.25	0.23	0.24	0.25	0.31	0.28
Average	...	...	0.22	...	...	0.30
Average Deviation	...	...	0.04	...	...	0.08
Maximum Deviation	...	..	+0.09	...	...	+0.16

Subcommittee XIII on Neutralization Number and Saponification (H. P. Ferguson, chairman) has conducted tests using the Tentative Method of Test for Neutralization Number of Petroleum Products by Color-Indicator Titration (D 663 - 42 T) both with and without the optional back titration with diluted H_2SO_4. These tests show that results are not the same by the two procedures (see Table VII) and the subcommittee has recommended that the optional back titration with H_2SO_4 be omitted from the method.

The subcommittee further recommends that the Proposed Method of Test for Saponification Number of Petroleum Products by Electrometric Titration, published as an appendix to the 1943 report of the committee, be republished as information.[1]

Subcommittee XV on Sampling and Gaging (A. E. Flowers, chairman) is recommending for publication as information the following, which appear in Appendices I and II of this report:

(*a*) Conversion Table for Petroleum Oils of Metric Tons in Vacuo to Long and Short Tons in Air, and

(*b*) Oil Measurement (A statement of principles that have been accepted for methods of oil measurement).

This subcommittee has a group on gaging under the chairmanship of L. C. Burroughs in which these recommendations originated. This group is cooperating with a corresponding group in the standardization committee of the Institute of Petroleum, Subcommittee 1 on Measurement and Sampling under the chairmanship of H. Hyams. The conversion table originated in Mr. Hyams' subcommittee.

Subcommittee XVIII on Aniline Point (Eugene Ayres, chairman) has conducted cooperative testing on a method for determining the mixed aniline point of high-solvency fractions using *n*-heptane as diluent. This method is recommended for incorporation in the Tentative Method of Test for Aniline Point of Petroleum Products (D 611 - 43 T) as described later. The experimental data are contained in Table VIII.

Subcommittee XXIV on Petroleum Sulfonates (V. F. Beyer, chairman) has developed a Proposed Method of Test for Analysis of Petroleum Sulfonates and recommended that the method be published as information only. This method appears as Appendix III to this report.

TABLE VIII.—SUMMARY OF DATA ON MIXED ANILINE POINT TESTS OF HIGH-SOLVENCY FRACTIONS USING n-HEPTANE AS DILUENT.

	Mixed Aniline Point, deg. Cent.[a]		
Laboratory	High-Solvency Naphtha X	High-Solvency Naphtha Y	Xylene
1	31.7	28.8	14.5
2	32.6	28.9	14.9
3	32.4	29.0	15.4
4	32.6	28.8	15.1
5	32.8	29.0	15.2
6	33.3	28.9	15.6
7	32.9	29.1	15.4
8	32.9	29.2	16.0
Average	32.6	29.0	15.3
Average deviation	0.3	0.1	0.3
Maximum deviation	0.9	0.2	0.8

[a] Each value in this table represents the average of two or more determinations that differ from their mean by not more than 0.2 C. Of these values, four (17 per cent) differ from the average of all laboratories by more than the 0.6 C. proposed as the reproducibility of the method for mixed aniline points.

Special Subcommittee on Coordination of Test Methods (F. D. Tuemmler, chairman) has prepared "Recommendations on the Form of A.S.T.M. Methods of Test for Petroleum Products and Lubricants," supplementary to the Society's general "Recommendations on the Form of Standards." It has proposed that this statement be made readily available for use by members of Committee D-2 in the preparation of new and revised methods of test. These recommendations on form are accordingly being published in the 1944 compilation of "A.S.T.M. Standards on Petroleum Products and Lubricants."

---

[1] See special compilation "A.S.T.M. Standards on Petroleum Products," October, 1944; also *Proceedings*, Am. Soc. Testing Mats., Vol. 43, p. 265 (1943).

Technical Committee A on Gasoline (C. B. Veal, chairman) is recommending that the Proposed Method of Test for Potential Gum in Aviation Gasoline, published in 1942, be revised as shown in the Appendix IV to conform to latest developments and published again for information only.

I. REVISIONS OF TENTATIVE STANDARDS

The committee recommends revision of six tentative standards as follows:

Tentative Method of Test for Aniline Point of Petroleum Products (**D 611 – 43 T**).[2]—A revision of the method, primarily to provide a procedure for mixed aniline points for high-solvency petroleum fractions using *n*-heptane as diluent, is recommended by Subcommittee XVIII on Aniline Point (Eugene Ayres, chairmen). The revised method is appended.[3]

Tentative Method of Test for Consistency of Lubricating Greases and Petrolatum (**D 217 – 38 T**).[4]—A revision of the method[3] separating the procedures for grease and petrolatum and incorporating minor changes is recommended by Subcommittee IV on Grease (F. E. Rosenstiehl, acting chairman). The revised method is appended.[3]

Tentative Method of Test for Knock Characteristics of Aviation Fuels (**D 614 – 43 T**).[2]—The following revisions are recommended by Section IV on Detonation (D. B. Brooks, chairman) of Technical Committee A:

Section 5 (*n*).—Change title to read "Fuel-Air Ratio for Maximum Thermal-Plug Temperature."

Section 5 (*p*).—Change lines 8 to 11 to read: ". . . until equal thermal-plug temperatures are obtained for the two fuels in a mean of three alternate comparisons, within a tolerance of 1.0 F. (0.6 C)." Also in lines 13 and 14 change "maximum knock mixture" to "the fuel-air ratio for maximum knock."

Section 7 (*a*).—In lines 12 and 13, change "mixture adjustment" to "readjustment of fuel-air ratio."

Section 7 (*b*).—Change title to "Adjustment of Fuel-Air Ratio." In item (*2*), line 3 change "air-fuel" to "fuel-air," in item (*3*), line 5 change "mixtures" to "fuel-air ratios," in item (*4*), line 6 change "maximum knock mixture" to "maximum thermal-plug temperature," and in line 11 delete "for maximum knock mixture."

Section 8 (*b*).—Change to "Adjustment of Fuel-Air Ratio.—The fuel level shall then be adjusted to obtain maximum thermal-plug temperature as described in Section 7 (*b*)."

Section 8 (*c*).—In lines 3 and 4 change "sample" to "fuel"; in lines 6 and 7 change "its maximum knock mixture" to "the fuel-air ratio for maximum thermal-plug temperature."

Section 9 (*a*).—In line 1 change "sample" to "fuel."

Section 9 (*b*).—Change from its present form: namely,

> (*b*) The rating of the test fuel shall be obtained by interpolation between the thermal-plug temperatures for the bracketing reference fuels.

to read as follows:

> (*b*) The thermal-plug temperature readings shall be averaged for the test fuel and for each of the reference fuel blends. The rating of the test fuel shall be found by interpolation from the averages so obtained.

Section 12.—In line 6 change "samples" to "fuels."

Section A4 (*c*).—Change to read as follows: "*Valve Guides*.—Cast iron. As installed, the difference in diameter between the valve stem and its guide shall be 0.0025 ± 0.0005 in. for the intake valve and 0.0035 ± 0.0005 in. for the exhaust valve."

---

[2] 1943 Supplement to Book of A.S.T.M. Standards, Part III.

[3] 1944 Book of A.S.T.M. Standards, Part III

[4] 1942 Book of A.S.T.M. Standards, Part III.

Section A5 (a).—At the end of the present section, add the following paragraph: "As a safety precaution, a suitable water manometer may be connected to the air outlet pipe of the ice tower. A differential pressure appreciably in excess of 0.5 in. of water indicates undue restriction of the air flow, resulting from improper condition of the ice or plugging of the drain trap."

Section A5 (e).—Change from its present form: namely,

> (*e*) *Carburetor Shields.*—A metal heat-insulating shield is inserted between the mixture heater and the carburetor with the concave side toward the manifold. A special copper-asbestos heat-insulating gasket 0.375 in. in thickness is used between the shield and the manifold and a standard copper-asbestos gasket between the shield and the carburetor.

to read as follows:

> (*e*) A polished stainless steel heat shield is installed between the carburetor and the intake manifold; with the curved section at the bottom, and with the concave side thereof toward the manifold. A standard copper-asbestos gasket is inserted between the shield and the carburetor, and a special copper-asbestos heat-insulating gasket 0.375 in. in thickness is used between the shield and the manifold.

Section A12.—From the end of the first sentence delete the phrase "resting, if possible, directly on the ground," and add the following sentence: "If at all possible, the engine should be located on the ground floor, and the foundation preferably should rest directly on the ground."

Section A13 (g).—Add a new sentence to read as follows: "In no case shall cylinders be rebored to more than 0.030 in. oversize."

Section A14.—Change the first sentence from its present form: namely,

> All engines shall be calibrated for volumetric clearance by the "tilt" method, which has been found accurate and reproducible.

to read as follows:

> The clearance volume of all engines shall be calibrated by the "tilt" method.

At the beginning of the first sentence in Paragraph (*b*), insert the word "and" before "loosen," and end the sentence after "base plate," deleting "and" and starting the second sentence with "Tilt the engine. . . ."

Tentative Method of Test for Neutralization Number of Petroleum Products by Color-Indicator Titration (**D 663 - 42 T**).[4]—A revision of this method, largely editorial in nature and eliminating back-titration of the sample, is recommended by Subcommittee XIII on Neutralization Number and Saponification (H. P. Ferguson, chairman). The revised method is entitled Tentative Method of Test for Acid and Base Numbers of Petroleum Products by Color-Indicator Titration.[3]

Tentative Method of Test for Neutralization Number of Petroleum Products by Electrometric Titration (**D 664 - 42 T**).[4]—A revision of this method, largely editorial in character, is recommended by Subcommittee XIII on Neutralization Number and Saponification (H. P. Ferguson, chairman). The revised method is entitled Tentative Method of Test for Acid and Base Numbers of Petroleum Products by Electrometric Titration.[3]

Tentative Method of Test for Rust-Preventing Characteristics of Steam-Turbine Oils in the Presence of Water (**D 665 - 42 T**).[4]—A revision of this method including the substitution of a round for the flat test specimen, stirring at 1000 instead of 750 rpm., and minor changes in cover and location of stirrer, is recommended by Technical Committee C on Turbine Oils (F. C. Linn, chairman). The revised method is appended.[3]

II. REVISIONS OF STANDARDS, IMMEDIATE ADOPTION

The committee recommends for immediate adoption revisions in three standard methods of test, as set forth below, and accordingly asks for a nine-tenths affirmative vote at the Annual Meeting in order that these modifications may be referred to letter ballot of the Society.

Standard Method of Test for Gum Content of Gasoline (**D 381 – 42**).[4]—The following editorial revisions are recommended by Technical Committee A on Gasoline (C. B. Veal, chairman):

Section 3 (*a*).—Change the third to sixth sentences, inclusive, to read as follows by the addition of the italicized words and figures and the omission of those in brackets:

> After washing, thoroughly dry both beakers by heating to about 302 F. (150 C.), and allow to cool simultaneously for the same period of time, but not less than 1 hr., in a [desiccator] *suitably covered vessel* (*Note 1*). [Do not use a drying agent in either the balance case or the desiccator.] Weigh the test beaker using the tare (Note *2*) on the opposite balance pan. After weighing, replace the tare beaker in the [desiccator] *vessel*, and place the test beaker in the well of the bath as shown in Fig. 1.

Add a new Note 1 to read as follows and renumber the present note as Note 2:

> NOTE 1.—The use of a drying agent in the covered vessel and in the balance case is not recommended.

Section 3 (*b*).—Change the fourth sentence to read as follows by the addition of the italicized words and the omission of the word in brackets: "Allow both test and tare beakers to cool simultaneously for the same period of time, but not less than 1 hr., in a [desiccator] *suitably covered vessel* under the same conditions as prescribed in Paragraph (*a*)."

Standard Method of Test for Sulfur in Petroleum Oils by Bomb Method (**D 129 – 39**).[4]—The following revision is recommended by Subcommittee VII on Sulfur (H. M. Hancock, chairman):

Section 6.—Change from its present form: namely,

> 6. *Reproducibility of Results.*—With care and proper attention to details, the percentages of sulfur obtained by the same operator with the same apparatus should not differ by more than 0.02 + 0.04 *A*; while the percentages obtained by different operators in different laboratories should not differ by more than 0.02 + 0.08 *A* (where *A* represents the average of the percentages obtained).

to read as follows:

> 6. *Reproducibility.*—Results should not differ from the mean by more than the following:

Sulfur Content, per cent	Same Operator and Apparatus	Different Operators and Apparatus
0 to 0.5	0.015	0.03
0.5 to 1.0	0.020	0.04
1.0 to 2.0	0.025	0.05
Above 2.0	0.035	0.07

Standard Method of Test for Viscosity by Means of the Saybolt Viscosimeter (**D 88 – 38**).[4]—The addition of the following note is recommended by Subcommittee V on Viscosity (J. C. Geniesse, chairman):

Section 2 (*c*).—Add a note at the end of this section to read as follows: "NOTE.—Many years' experience with flasks conforming to these dimensions has proved them to be satisfactory for all but the most viscous oils. With the latter, drainage errors may occur if the length of the neck of the flask above the graduation mark varies excessively. As soon as stocks of flasks now on hand have been depleted, it is planned to revise the flask specification by limiting the length of the neck above the graduation mark to a maximum of 11 mm."

III. ADOPTION OF TENTATIVE STANDARDS AS STANDARDS

The committee recommends that the following four tentative standards be approved for reference to letter ballot of the Society for adoption as standard:

Tentative Method of Test for Oil Content of Paraffin Wax (**D 721 – 43 T**),[2] on the recommendation of Subcommittee III on Paraffin Wax (L. C. Beard, Jr., chairman).

Tentative Method of Test for Knock Characteristics of Motor Fuels (**D 357 – 43 T**),[2] on the recommendation of Technical Committee A on Gasoline (C. B. Veal, chairman), revised as follows:

Section 5 (*c*).—In line 1 change "0.025 in." to "0.015 to 0.025 in." Insert new Note 2 to read as follows: "NOTE 2.—In rating fuels of very high octane number, more satisfactory operation of spark plugs is obtained with a gap of less than 0.025 in., the latter being preferable in the motor-fuel range.

Section 5 (*o*).—Change title to "Fuel-Air Ratio for Maximum Knock."

Footnote 7.—Insert subscript "e" after each symbol in the present formula and add the following formula before the last paragraph in the footnote:

> The analogous formula for metric barometers is:
>
> $$B_m = B'_m - 0.00016\, B'_m t_m$$
>
> where B'_m = observed barometric pressure in millimeters of mercury, and
>
> t_m = observed temperature of barometer in degrees Centigrade.

Section 9.—Change the first sentence from its present form: namely,

> For inspection and preliminary adjustment in accordance with the manufacturer's instructions the bouncing-pin shall be removed from the engine.

to read as follows:

> Preliminary adjustment of the bouncing-pin shall be made in accordance with the manufacturer's instructions before the pin is placed in the engine.

In the last sentence of the first paragraph, change the word "replaced" to read "placed."

Section 9 (*b*).—Delete and substitute the following: "The bouncing-pin adjustment shall not be considered satisfactory unless the knock-meter reading is zero when operating on a non-knocking reference fuel throughout the micrometer range over which the pin setting is to be used."

Section 11 (*a*).—Change "adjustment" to "readjustment." In the first sentence, change "fuel sample" to "test fuel."

Section 11 (*b*).—Change title to "Adjustment of Fuel-Air Ratio." In line 10 change "air-fuel" to "fuel-air," and in line 11 change "air-fuel" to "fuel-air."

Section 12 (*b*).—Change title to "Adjustment of Fuel-Air Ratio."

Section 12 (*d*).—In line 1 change "air-fuel" to "fuel-air."

Section 13.—In the first sentence, change "test sample" to read "test fuel."

Section A4 (*c*).—Change this section to read as follows: "(*c*) *Valve Guides.*—Cast iron. As installed, the difference in diameter between the valve stem and its guide shall be 0.0025 ± 0.0005 in. for the intake valve and 0.0035 ± 0.0005 in. for the exhaust valve."

Section A4 (*f*).—In the first sentence insert the word "reference" before "fuel."

Section A5 (*a*).—At the end of the present section, add the following new paragraph: "As a safety precaution, a suitable water manometer may be connected to the air-outlet pipe of the ice tower. A differential pressure appreciably in excess of 0.5 in. of water indicates undue restriction of the air flow, resulting from improper condition of the ice or plugging of the drain trap."

Section A5 (*e*).—Change from its present form: namely,

> (*e*) *Heat Shield.*—A polished stainless steel heat shield is furnished which shall be installed with the plate downward and with the concave side toward the manifold between the carburetor and the intake manifold with a standard copper-asbestos gasket between the shield and the carburetor and a special copper-asbestos heat insulating gasket 0.375 in. in thickness between the shield and the manifold.

to read as follows:

> (*e*) *Heat Shield.*—A polished stainless steel heat shield is installed between the carburetor

and the intake manifold, with the curved section at the bottom, and with the concave side thereof toward the manifold. A standard copper-asbestos gasket is inserted between the shield and the carburetor, and a special copper-asbestos heat-insulating gasket 0.375 in. in thickness is used between the shield and the manifold.

Footnote 16.—Change from its present form: namely,

> [16] Note that the throttle plate heretofore inserted between the carburetor and intake manifold has been discarded in the present method.

to read as follows:

> [16] Note that the throttle plate originally used with the present type variable-float-level carburetor has been discarded.

Section A8.—Add a new Paragraph (*d*) to read as follows:

> (*d*) *Valve Lubrication.*—A valve oiling tray is provided for lubricating the intake and exhaust valve stems. A felt washer is used on the exhaust valve stem only.

Section A12.—From the end of the first sentence delete the phrase "resting, if possible, directly on the ground," and add the following sentence: "If at all possible, the engine should be located on the ground floor, and the foundation preferably should rest directly on the ground."

Section A13 (*g*).—In the fifth line change "oil" to ", or oil."

Section A13 (*h*).—Change the first sentence to read as follows by the addition of the italicized words and figures and the omission of the words in brackets:

> The cylinder shall be replaced (or rebored for routine testing) when it shows a wear of 0.006 in. [or loses compression due to being out of round] *or a taper of 0.004 in., or is 0.0025 in. out of round.* In no case shall cylinders be rebored to more than 0.03*0* in. oversize.

Section A15.—Change the first sentence from its present form: namely,

> All engines shall be calibrated for volumetric clearance by the "tilt" method, which has been found accurate and reproducible.

to read as follows:

> The clearance volume of all engines shall be calibrated by the "tilt" method.

At the beginning of the first sentence in Paragraph (*b*), insert the word "and" before "loosen," and end the sentence after "base plate," deleting "and" and starting the second sentence with "Tilt the engine. . . ."

Footnote 19.—Delete the last sentence which reads: "This equipment may be purchased through the Waukesha Motor Co."

Tentative Method of Test for Saponification Number of Petroleum Products by Color-Indicator Titration (**D 94 – 43 T**),[2] on the recommendation of Subcommittee XIII on Neutralization Number and Saponification (H. P. Ferguson, chairman), revised editorially as follows:

Section 5 (*a*).—Change to read as follows:

> 5. (*a*) *Alcoholic Potassium Hydroxide* (*0.5 N*).—Prepare 0.5 *N* solution by dissolving KOH "purified by alcohol" in the alcohol specified in Paragraph (*b*). Allow the solution to settle in a dark place. Filter the solution, allow to stand for 24 hr. and standardize to 0.5 *N*.

Section 6.—After "A.S.T.M. precipitation naphtha" in the fourth sentence add "(see Note 2, Section 8)."

Section 7.—Change from its present form: namely,

> 7. A 2- to 3-g. sample may be used for fats, and samples of larger size for oils containing fats or fatty oils. The size of the sample shall be so chosen that the back-titration is from 40 to 80 per cent of the blank, except that the weight of sample shall not exceed 20 g.

to read as follows:

> 7. The size of the sample shall be chosen so that the back-titration is from 40 to 80 per cent of the blank, except that the weight of the sample shall not exceed 20 g. (Note 1).
>
> NOTE 1.—The size of sample depends upon the amount of saponifiable matter present. A 4- to 20-g. sample is generally required for blends of mineral oils and fats or fatty oils. If the method is used for fats or fatty oils alone, a 1- to 2-g.

sample is generally required for materials having a saponification number higher than 210, and a 2- to 3-g. sample for materials having a saponification number lower than 210.

The above recommendation on Method D 94 is submitted jointly with Committee D-9 on Electrical Insulating Materials.

TABLE IX.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. REVISIONS OF TENTATIVE STANDARDS			
Test for Aniline Point of Petroleum Products (D 611 – 43 T)	48	0	5
Test for Consistency of Lubricating Greases and Petrolatum (D 217 – 38 T)	43	0	6
Test for Knock Characteristics of Aviation Fuels (D 614 – 43 T)	33	0	16
Test for Neutralization Number of Petroleum Products by Color-Indicator Titration (D 663 – 42 T)	48	1	4
Test for Neutralization Number of Petroleum Products by Electrometric Titration (D 664 – 42 T)	45	0	8
Test for Rust-Preventing Characteristics of Turbine Oils (D 665 – 42 T)	37	3	13
II. REVISIONS OF STANDARDS, IMMEDIATE ADOPTION			
Test for Gum Content of Gasoline (D 381 – 42)	43	0	10
Test for Sulfur in Petroleum Oils by Bomb Method (D 129 – 39)	49	0	4
Test for Viscosity by means of the Saybolt Viscosmeter (D 88 – 38)	45	1	3
III. ADOPTION OF TENTATIVE STANDARDS AS STANDARDS			
Test for Oil Content of Paraffin Wax (D 721 – 43 T)	42	0	11
Test for Knock Characteristics of Motor Fuels (D 357 – 43 T), as revised	34	0	15
Test for Saponification Number of Petroleum Products (D 94 – 43 T), as revised	48	0	5
Conversion of Kinematic Viscosity to Saybolt Furol Viscosity (D 666 – 42 T)	49	0	4
IV. WITHDRAWAL OF TENTATIVE STANDARD			
Specifications for Aviation Gasoline (D 615 – 41 T)	38	0	15

Tentative Method for Conversion of Kinematic Viscosity to Saybolt Furol Viscosity (**D 666 – 42 T**),[4] on the recommentation of Subcommittee V on Viscosity (J. C. Geniesse, chairman).

IV. WITHDRAWAL OF TENTATIVE STANDARD

The committee recommends the withdrawal of the Tentative Specifications for Aviation Gasolines (D 615 – 41 T)[4] as proposed by Technical Committee A on Gasoline (C. B. Veal, chairman). It is impractical to keep specifications for this commodity in conformity with practice under present wartime conditions.

V. TENTATIVE STANDARDS CONTINUED AS TENTATIVE

The following tentative standards have remained in the tentative status for two years or longer without revision:

Test for Color of Lubricating Oil and Petrolatum by Means of the A.S.T.M. Union Colorimeter (D 155 – 39 T),
Test for Kinematic Viscosity (D 445 – 42 T),
Test for Sediment in Fuel Oil by Extraction (D 473 – 38 T),
Test for Sulfur in Petroleum Oils by Lamp Method (D 90 – 41 T),
Test for Oxidation Stability of Gasoline (D 525 – 42 T),
Specifications for Fuel Oils (D 396 – 39 T), and
Specifications for Gasoline (D 439 – 40 T).

It is recommended that these tentative standards be continued in the tentative status because further developments are in progress or in prospect.

VI. STANDARDS SIX YEARS WITHOUT REVISION

The following standards have been published for six years or longer without revision and are considered by the committee to be in accord with present practice and to require no revision:

Test for Autogenous Ignition Temperatures of Petroleum Products (D 286 – 30),
Test for Burning Quality of Long-Time Burning Oil for Railway Use (D 219 – 36),
Test for Burning Quality of Mineral Seal Oil (D 239 – 30),
Test for Color of Refined Petroleum Oil by Means of Saybolt Chromometer (D 156 – 38),

Test for Dilution of Crankcase Oils (D 322 - 35),
Test for Steam Emulsion of Lubricating Oils (D 157 - 36),
Test for Flash and Fire Points by Means of Open Cup (D 92 - 33),
Test for Flash Point by Means of the Tag Closed Tester (D 56 - 36),
Test for Melting Point of Petrolatum (D 127 - 30),
Sampling Petroleum and Petroleum Products (D 270 - 33),
Test for Detection of Free Sulfur and Corrosive Sulfur Compounds in Gasoline (D 130 - 30),
Abridged Volume Correction Table for Petroleum Oils (D 206 - 36).

The present officers of the committee were re-elected for the ensuing term of two years.

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 73 voting members, with the results shown in Table IX.

This report has been submitted to letter ballot of the committee which consists of 73 voting members; 53 members returned their ballots, of whom 52 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the committee,

T. A. BOYD,
Chairman.

R. P. ANDERSON,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-2 presented to the Society through Committee E-10 on Standards a proposed Emergency Method for Determination of Isopentane and Benzene Insolubles in Used Lubricating Oil and proposed Emergency Alternate Provisions in the Standard Method of Test for Cloud and Pour Points (D 97 - 39). The emergency standard and emergency alternate provisions were accepted by Committee E-10 on August 28, 1944, and assigned the A.S.T.M. serial designations ES - 42 and EA - D 97, respectively. They appear in the 1944 Book of A.S.T.M. Standards, Part III.

On October 3, 1944, Committee E-10 accepted the recommendation of Committee D-2 that the following methods of test be issued as tentative:

Tentative Methods of Test for:
Chlorine in Lubricating Oils by Bomb Method (D 808 - 44 T) [formerly issued as Emergency Standard ES - 36],
Phosphorus in Lubricating Oils (D 809 - 44 T) [formerly issued as Emergency Standard ES - 37],
Lead, Copper, and Iron in Lubricating Oils (D 810 - 44 T) [formerly issued as Emergency Standard ES - 38], and
Metals in Lubricating Oils (D 811 - 44 T) [formerly issued as Emergency Standard ES - 39].

These new tentative standards, assigned the A.S.T.M. serial designations indicated above, appear in the 1944 Book of A.S.T.M. Standards, Part III.

APPENDIX I

CONVERSION TABLES FOR PETROLEUM OILS OF METRIC TONS IN VACUO TO LONG AND SHORT TONS IN AIR

There has been some concern expressed in the oil industry regarding discrepancies which arise when attempting to convert short or long tons of petroleum products to equivalents in metric weights. In many instances these discrepancies have been found to be due to the fact that while metric tonnages of bulk oil are frequently in effect, "weights in vacuo" American and British short or long tons are "apparent weights in air." It cannot be considered correct practice to convert a metric ton in vacuo to a short ton in air by applying the established factor 1 metric ton = 1.1023 short tons because this latter ratio presupposes that either the two types of weights are "apparent weighings in air" or both weighings have been corrected for air buoyancy.

In view of the need for uniform accurate conversion factors the following Tables I, A and B are published. The Institute of Petroleum (England) from whom these tables were received also intends to publish them and it is hoped that this joint action will help in establishing these tables for standard worldwide usage.

TABLE I.—FACTORS FOR CONVERTING METRIC TONS IN VACUO TO LONG AND SHORT TONS IN AIR AND *VICE VERSA*.

Specific Gravity 60/60 F.	Metric Tons in Vacuo to Long Tons in Air	Long Tons in Air to Metric Tons in Vacuo	Metric Tons in Vacuo to Short Tons in Air	Short Tons in Air to Metric Tons in Vacuo	Specific Gravity 60/60 F.	Metric Tons in Vacuo to Long Tons in Air	Long Tons in Air to Metric Tons in Vacuo	Metric Tons in Vacuo to Short Tons in Air	Short Tons in Air to Metric Tons in Vacuo	Specific Gravity 60/60 F.	Metric Tons in Vacuo to Long Tons in Air	Long Tons in Air to Metric Tons in Vacuo	Metric Tons in Vacuo to Short Tons in Air	Short Tons in Air to Metric Tons in Vacuo
A. IMPERIAL SYSTEM—BRITISH STANDARD AIR, 62 F., 66⅔ PERCENT RELATIVE HUMIDITY														
0.584 to 0.586	0.98230	1.01802	1.10018	0.90895	0.683 to 0.686	0.98260	1.01772	1.10051	0.90868	0.823 to 0.828	0.98290	1.01740	1.10085	0.90840
0.587 to 0.589	0.98231	1.01801	1.10019	0.90894	0.687 to 0.690	0.98261	1.01771	1.10052	0.90867	0.829 to 0.834	0.98291	1.01739	1.10086	0.90839
0.590 to 0.592	0.98232	1.01800	1.10020	0.90893	0.691 to 0.694	0.98262	1.01770	1.10053	0.90866	0.835 to 0.840	0.98292	1.01738	1.10087	0.90838
0.593 to 0.595	0.98233	1.01790	1.10021	0.90892	0.695 to 0.698	0.98263	1.01769	1.10055	0.90865	0.841 to 0.846	0.98293	1.01737	1.10088	0.90837
0.596 to 0.598	0.98234	1.01798	1.10022	0.90891	0.699 to 0.702	0.98264	1.01768	1.10056	0.90865	0.847 to 0.852	0.98294	1.01736	1.10089	0.90836
0.599 to 0.601	0.98235	1.01797	1.10023	0.90890	0.703 to 0.706	9.98265	1.01767	1.10057	0.90864	0.853 to 0.858	0.98295	1.01735	1.10090	0.90835
0.602 to 0.604	0.98236	1.01796	1.10024	0.90890	0.707 to 0.711	0.98266	1.01766	1.10058	0.90863	0.859 to 0.864	0.98296	1.01734	1.10092	0.90834
0.605 to 0.607	0.98237	1.01795	1.10025	0.90889	0.712 to 0.715	0.98267	1.01765	1.10059	0.90862	0.865 to 0.870	0.98297	1.01733	1.10093	0.90833
0.608 to 0.610	0.98238	1.01794	1.10027	0.90888	0.716 to 0.719	0.98268	1.01764	1.10060	0.90861	0.871 to 0.876	0.98298	1.01732	1.10094	0.90832
0.611 to 0.613	0.98239	1.01793	1.10028	0.90887	0.720 to 0.723	0.98269	1.01763	1.10061	0.90860	0.877 to 0.883	0.98299	1.01731	1.10095	0.90832
0.614 to 0.616	0.98240	1.01792	1.10029	0.90886	0.724 to 0.728	0.98270	1.01762	1.10062	0.90859	0.884 to 0.889	0.98300	1.01730	1.10096	0.90831
0.617 to 0.619	0.98241	1.01791	1.10030	0.90885	0.729 to 0.732	0.98271	1.01761	1.10064	0.90858	0.890 to 0.896	0.98301	1.01729	1.10097	0.90830
0.620 to 0.622	0.98242	1.01790	1.10031	0.90884	0.733 to 0.737	0.98272	1.01760	1.10065	0.90857	0.897 to 0.903	0.98302	1.01728	1.10098	0.90829
0.623 to 0.626	0.98243	1.01789	1.10032	0.90883	0.738 to 0.741	0.98273	1.01758	1.10066	0.90856	0.904 to 0.910	0.98303	1.01727	1.10099	0.90828
0.627 to 0.629	9.98244	1.01788	1.10033	0.90882	0.742 to 0.746	0.98274	1.01757	1.10067	0.90855	0.911 to 0.917	0.98304	1.01726	1.10100	0.90827
0.630 to 0.632	0.98245	1.01787	1.10034	0.90882	0.747 to 0.751	0.98275	1.01756	1.10068	0.90854	0.918 to 0.924	0.98305	1.01725	1.10102	0.90826
0.633 to 0.636	0.98246	1.01786	1.10036	0.90881	0.752 to 0.755	0.98276	1.01755	1.10069	0.90853	0.925 to 0.931	0.98306	1.01724	1.10103	0.90825
0.637 to 0.639	0.98247	1.01785	1.10037	0.90880	0.756 to 0.760	0.98277	1.01754	1.10070	0.90852	0.932 to 0.938	0.98307	1.01723	1.10104	0.90824
0.640 to 0.642	0.98248	1.01784	1.10038	0.90879	0.761 to 0.765	0.98278	1.01753	1.10071	0.90851	0.939 to 0.945	0.98308	1.01722	1.10105	0.90824
0.643 to 0.646	0.98249	1.01783	1.10039	0.90878	0.766 to 0.770	0.98279	1.01752	1.10072	0.90850	0.946 to 0.953	0.98309	1.01721	1.10106	0.90823
0.647 to 0.649	0.98250	1.01782	1.10040	0.90877	0.771 to 0.775	0.98280	1.01751	1.10074	0.90849	0.954 to 0.960	0.98310	1.01720	1.10107	0.90822
0.650 to 0.653	0.98251	1.01781	1.10041	0.90876	0.776 to 0.780	0.98281	1.01750	1.10075	0.90849	0.961 to 0.968	0.98311	1.01719	1.10108	0.90821
0.654 to 0.656	0.98252	1.01780	1.10042	0.90875	0.781 to 0.785	0.98282	1.01749	1.10076	0.90848	0.969 to 0.976	0.98312	1.01718	1.10109	0.90820
0.657 to 0.660	0.98253	1.01779	1.10043	0.90874	0.786 to 0.790	0.98283	1.01747	1.10077	0.90846	0.977 to 0.984	0.98313	1.01717	1.10111	0.90819
0.661 to 0.664	0.98254	1.01778	1.10044	0.90874	0.791 to 0.795	0.98284	1.01746	1.10078	0.90845	0.985 to 0.992	0.98314	1.01716	1.10112	0.90818
0.665 to 0.667	0.98255	1.01777	1.10046	0.90873	0.796 to 0.801	0.98285	1.01745	1.10079	0.90844	0.993 to 1.000	0.98315	1.01715	1.10113	0.90817
0.668 to 0.671	0.98256	1.01776	1.10047	0.90872	0.802 to 0.806	0.98286	1.01744	1.10080	0.90843	1.001 to 1.009	0.98316	1.01714	1.10114	0.90816
0.672 to 0.675	0.98257	1.01775	1.10048	0.90871	0.807 to 0.811	0.98287	1.01743	1.10081	0.90842	1.010 to 1.017	0.98317	1.01713	1.10115	0.90815
0.676 to 0.679	0.98258	1.01774	1.10049	0.90870	0.812 to 0.817	0.98288	1.01742	1.10083	0.90841	1.018 to 1.026	0.98318	1.01712	1.10116	0.90815
0.680 to 0.682	0.98259	1.01773	1.10050	0.90869	0.818 to 0.822	0.98289	1.01741	1.10084	0.90840	1.027 to 1.035	0.98319	1.01711	1.10117	0.90814
										1.036 to 1.044	0.98320	1.01710	1.10118	0.90813
										1.045 to 1.053	0.98321	1.01709	1.10120	0.90812

B. UNITED STATES SYSTEM—NATIONAL BUREAU OF STANDARDS AIR, 60 F., 50 PERCENT RELATIVE HUMIDITY

0.584 to 0.586	0.98230	1.01802	1.10018	0.90895	0.684 to 0.687	0.98260	1.01772	1.10051	0.90868	0.824 to 0.829	0.98290	1.01740	1.10085	0.90840
0.587 to 0.589	0.98231	1.01801	1.10019	0.90894	0.688 to 0.691	0.98261	1.01771	1.10052	0.90867	0.830 to 0.835	0.98291	1.01739	1.10086	0.90839
0.590 to 0.592	0.98232	1.01800	1.10020	0.90893	0.692 to 0.695	0.98262	1.01770	1.10053	0.90866	0.836 to 0.841	0.98292	1.01738	1.10087	0.90838
0.593 to 0.595	0.98233	1.01799	1.10021	0.90892	0.696 to 0.699	0.98263	1.01769	1.10055	0.90865	0.842 to 0.846	0.98293	1.01737	1.10088	0.90837
0.596 to 0.598	0.98234	1.01798	1.10022	0.90891	0.700 to 0.703	0.98264	1.01768	1.10056	0.90865	0.847 to 0.852	0.98294	1.01736	1.10089	0.90836
0.599 to 0.601	0.98235	1.01797	1.10023	0.90890	0.704 to 0.707	0.98265	1.01767	1.10057	0.90864	0.853 to 0.859	0.98295	1.01735	1.10090	0.90835
0.602 to 0.604	0.98236	1.01796	1.10024	0.90890	0.708 to 0.711	0.98266	1.01766	1.10058	0.90863	0.860 to 0.865	0.98296	1.01734	1.10092	0.90834
0.605 to 0.607	0.98237	1.01795	1.10025	0.90889	0.712 to 0.715	0.98267	1.01765	1.10059	0.90862	0.866 to 0.871	0.98297	1.01733	1.10093	0.90833
0.608 to 0.610	0.98238	1.01794	1.10027	0.90888	0.716 to 0.720	0.98268	1.01764	1.10060	0.90861	0.872 to 0.877	0.98298	1.01732	1.10094	0.90832
0.611 to 0.613	0.98239	1.01793	1.10028	0.90887	0.721 to 0.724	0.98269	1.01763	1.10061	0.90860	0.878 to 0.884	0.98299	1.01731	1.10095	0.90832
0.614 to 0.616	0.98240	1.01792	1.10029	0.90886	0.725 to 0.728	0.98270	1.01762	1.10062	0.90859	0.885 to 0.890	0.98300	1.01730	1.10096	0.90831
0.617 to 0.619	0.98241	1.01791	1.10030	0.90885	0.729 to 0.733	0.98271	1.01761	1.10064	0.90858	0.891 to 0.897	0.98301	1.01729	1.10097	0.90830
0.620 to 0.622	0.98242	1.01790	1.10031	0.90884	0.734 to 0.737	0.98272	1.01760	1.10065	0.90857	0.898 to 0.904	0.98302	1.01728	1.10098	0.90829
0.623 to 0.626	0.98243	1.01789	1.10032	0.90883	0.738 to 0.742	0.98273	1.01758	1.10066	0.90856	0.905 to 0.911	0.98303	1.01727	1.10099	0.90828
0.627 to 0.629	0.98244	1.01788	1.10033	0.90882	0.743 to 0.746	0.98274	1.01757	1.10067	0.90855	0.912 to 0.918	0.98304	1.01726	1.10100	0.90827
0.630 to 0.632	0.98245	1.01787	1.10034	0.90882	0.747 to 0.751	0.98275	1.01756	1.10068	0.90854	0.919 to 0.925	0.98305	1.01725	1.10102	0.90826
0.633 to 0.636	0.98246	1.01786	1.10036	0.90881	0.752 to 0.756	0.98276	1.01755	1.10069	0.90853	0.926 to 0.932	0.98306	1.01724	1.10103	0.90825
0.637 to 0.639	0.98247	1.01785	1.10037	0.90880	0.757 to 0.761	0.98277	1.01754	1.10070	0.90852	0.933 to 0.939	0.98307	1.01723	1.10104	0.90824
0.640 to 0.642	0.98248	1.01784	1.10038	0.90879	0.762 to 0.765	0.98278	1.01753	1.10071	0.90851	0.940 to 0.947	0.98308	1.01722	1.10105	0.90824
0.643 to 0.646	0.98249	1.01783	1.10039	0.90878	0.766 to 0.770	0.98279	1.01752	1.10072	0.90850	0.948 to 0.954	0.98309	1.01721	1.10106	0.90823
0.647 to 0.649	0.98250	1.01782	1.10040	0.90877	0.771 to 0.775	0.98280	1.01751	1.10074	0.90849	0.955 to 0.962	0.98310	1.01720	1.10107	0.90822
0.650 to 0.653	0.98251	1.01781	1.10041	0.90876	0.776 to 0.780	0.98281	1.01750	1.10075	0.90849	0.963 to 0.970	0.98311	1.01719	1.10108	0.90821
0.654 to 0.656	0.98252	1.01780	1.10042	0.90875	0.781 to 0.785	0.98282	1.01749	1.10076	0.90848	0.971 to 0.978	0.98312	1.01718	1.10109	0.90820
0.657 to 0.660	0.98253	1.01779	1.10043	0.90874	0.786 to 0.791	0.98283	1.01747	1.10077	0.90846	0.979 to 0.986	0.98313	1.01717	1.10111	0.90819
0.661 to 0.664	0.98254	1.01778	1.10044	0.90874	0.792 to 0.796	0.98284	1.01746	1.10078	0.90845	0.987 to 0.994	0.98314	1.01716	1.10112	0.90818
0.665 to 0.667	0.98255	1.01777	1.10046	0.90873	0.797 to 0.801	0.98285	1.01745	1.10079	0.90844	0.995 to 1.002	0.98315	1.01715	1.10113	0.90817
0.668 to 0.671	0.98256	1.01776	1.10047	0.90872	0.802 to 0.807	0.98286	1.01744	1.10080	0.90843	1.003 to 1.010	0.98316	1.01714	1.10114	0.90816
0.672 to 0.675	0.98257	1.01775	1.10048	0.90871	0.808 to 0.812	0.98287	1.01743	1.10081	0.90842	1.011 to 1.019	0.98317	1.01713	1.10115	0.90815
0.676 to 0.679	0.98258	1.01774	1.10049	0.90870	0.813 to 0.818	0.98288	1.01742	1.10083	0.90841	1.020 to 1.028	0.98318	1.01712	1.10116	0.90815
0.680 to 0.683	0.98259	1.01773	1.10050	0.90869	0.819 to 0.823	0.98289	1.01741	1.10084	0.90840	1.029 to 1.037	0.98319	1.01711	1.10117	0.90814
										1.038 to 1.046	0.98320	1.01710	1.10118	0.90813
										1.047 to 1.055	0.98321	1.01709	1.10120	0.90812

APPENDIX II

OIL MEASUREMENT

The Institute of Petroleum's Committee 1 on Measurement and Sampling of Oil, and the American Society for Testing Materials Committee D-2, Subcommittee XV on Sampling and Gaging, have undertaken cooperative work to establish oil measurement procedures and standards which would be acceptable in both the British Empire and the United States. Such codes would eliminate major differences in oil measurement methods as practiced in England and the United States thereby aiding in the establishment of world-wide uniformity of measurement procedure. The following "Principles" have been agreed upon by the two committees to serve as a guide to govern their individual detailed work.

Normal Measurement:

1. Defining "normal" measurement as those processes using gaging tape, thermometer, and hydrometer, which are applicable to petroleum liquids in bulk in the gasoline-to-thin-fuel range, there is then only one fundamental operation, the determination of oil volume in a vessel. Quantities received or delivered are calculated as differences between such measured volumes.

When several containers (tanks, pipelines, tankers, etc.) are involved, several separate quantities may be summed into a single total. Containers like pipelines do not lend themselves to the normal gaging process, and so are most conveniently handled either completely full or empty; but there is still only one fundamental process.

Quantity of Oil:

2. A quantity figure will be substantially correct if—

(*a*) The accepted oil temperature, and
(*b*) The accepted oil gravity

are fair averages for the container's contents. This implies that:

(*c*) The container must be adequately sampled.

Further:

The accepted oil volume must be substantially correct. This implies that:

(*d*) The measured oil depth (innage or ullage) and
(*e*) The capacity tables for the container are substantially correct.

Finally:

(*f*) All calculations, including any corrections applied, must be substantially correct also.

NOTE.—"Substantially" means "within the limits of uncertainty to be laid down by the Committee," and "accepted" means the "figure taken into further calculation."

There are no other factors involved in "normal" measurement; complete discussion must cover all items given.

Exceptional Cases:

3. Substantial modification of the normal method of measurement or even specially designed methods will usually be necessary if the product concerned is:

(*a*) Gaseous (natural gas),
(*b*) Liquid only under pressure (propane, butane),
(*c*) Notably volatile (crudes, light gasolines),
(*d*) Notably viscous (thick fuels, thin bitumens, emulsions),
(*e*) Solid, or practically so (coke, carbon, some bitumens);

or contains undissolved:

(*f*) Cases (bitumens),

(*g*) Liquids (wet crudes, bitumen and other emulsions),

(*h*) Solids (sand and wax in crudes, asphalts containing stone dust);

or if it is:

(*i*) At high temperature (heated fuel oils),

(*j*) Not in bulk (canned or drummed),

(*k*) Contains alcohol, benzol, or other materials not derived from petroleum.

Again:

(*l*) Methods may have to be considered in which the usual tank capacity table is replaced by the use of a meter, the measurement of specific gravity by measurement of oil head, and so on.

The normal method may require modification if receipt or delivery of only a small fraction of a tank's contents is to be measured by difference.

Methods:

4. (*a*) Preference shall be given to measurement by volume at 60 F. and data should preferably be reduced along the lines of the National Standard Petroleum Oil Tables, National Bureau of Standards *Circular C 410.*

(*b*) Standard methods for measurement by weight may also be required for use:

(*1*) With ships' cargo quantities,

(*2*) When local official regulations require this, or

(*3*) Where there is long-standing commercial practice.

(*c*) Current British practice calculates weights by taking ten times the specific gravity of the oil as being the weight of an Imperial gallon, expressed in pounds and decimals. This may have to be accepted for routine work, even if the standard method is laid down to follow *Circular C 410.*

Precision:

5. The attitude of the committee is that no simple precaution which tends to improve accuracy should be omitted, but that this must not involve the present relatively simple instruments (gaging tape, thermometer, hydrometer, and so on) being replaced by others more complex, nor should precautions with present instruments be carried so far that procedures become cumbrous. The construction and standardization of all oil measurement equipment should, however, be carefully specified.

APPENDIX III

PROPOSED METHOD OF ANALYSIS OF PETROLEUM SULFONATES[1]

This is a proposed method and is published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 260 S. Broad St., Philadelphia 2, Pa.

Scope

1. This method of analysis covers procedures for the determination of mineral oil, sodium sulfonate, carboxylate soap, inorganic salt, free alkali content, combining weight, and specific gravity of crude and refined petroleum sulfonates. It is also applicable, with slight modification, to potassium and ammonium sulfonates.

Outline of Method

2. This method of analysis of petroleum sulfonates is outlined in Fig. 1.

Apparatus

3. (*a*) *Vacuum Oven* capable of operating at 70 to 100 C. under 3 mm. of mercury absolute pressure.

(*b*) *Beaker*, glass, with inverted rim, turned in 10 mm. from wall of beaker and pointed downward to a point 5 mm. below shoulder, 65 to 75 mm. in diameter, 75 to 85 mm. in height, and wall thickness (approximately 1 mm.) such that weight is less than 70 g.

(*c*) *Steam Bath.*

(*d*) *Muffle Furnace* capable of operating at 800 ± 50 C.

(*e*) *Atmospheric Ovens* capable of being maintained at 120 C. and at 70 to 75 C.

(*f*) *Desalting Funnel* as shown in Fig. 2.

(*g*) *Water Bath* capable of being maintained at 40 to 50 C and at 25 ± 0.2 C.

(*h*) *Vacuum Desiccator*, shielded.

(*i*) *Distillation Apparatus* as described in A.S.T.M. Method D 95–40 Test for Water in Petroleum Products and Other Bituminous Materials.[2]

(*j*) *Crucible*, platinum, 35 to 40-ml. capacity.

(*k*) *Pycnometer* as shown in Fig. 3. To calibrate, weigh to 1 mg. with cap in place, then fill with distilled water at 15 to 20 C. and place in a water bath at 25 ± 0.2 C. After 30 min., adjust the water meniscus at the top of the neck so it is exactly level. (To obtain a flat meniscus add a minute amount of wetting agent to the water surface.) Remove the pycnometer from the bath, cool to 25 C., and dry the outside. Cap and weigh to 1 mg. Record the water weight as W_c.

Reagents

4. (*a*) *Sodium Carbonate*, anhydrous.

(*b*) *Sodium Sulfate*, anhydrous, crystalline.

(*c*) *Sodium Sulfate Solution (20 per cent).*

(*d*) *Hydrochloric Acid (12 N).*

(*e*) *Nitric Acid (16 N).*

(*f*) *Sulfuric Acid (36 N, and 0.5 N standard).*

---

[1] **This proposed method is under the jurisdiction of the A.S.T.M. Committee D-2 on Petroleum Products and Lubricants. Published as information, October, 1944.**

[2] 1944 Book of A.S.T.M. Standards, Part III.

(*g*) *Methyl Orange Indicator Solution (0.1 per cent, aqueous).*

(*h*) *Phenolphthalein Indicator Solution (1 per cent in 50 per cent ethyl alcohol).*

(*n*) *Petroleum Ether.*—Boiling range, 30 to 75 C.; maximum nonvolatile impurities, 0.002 per cent.

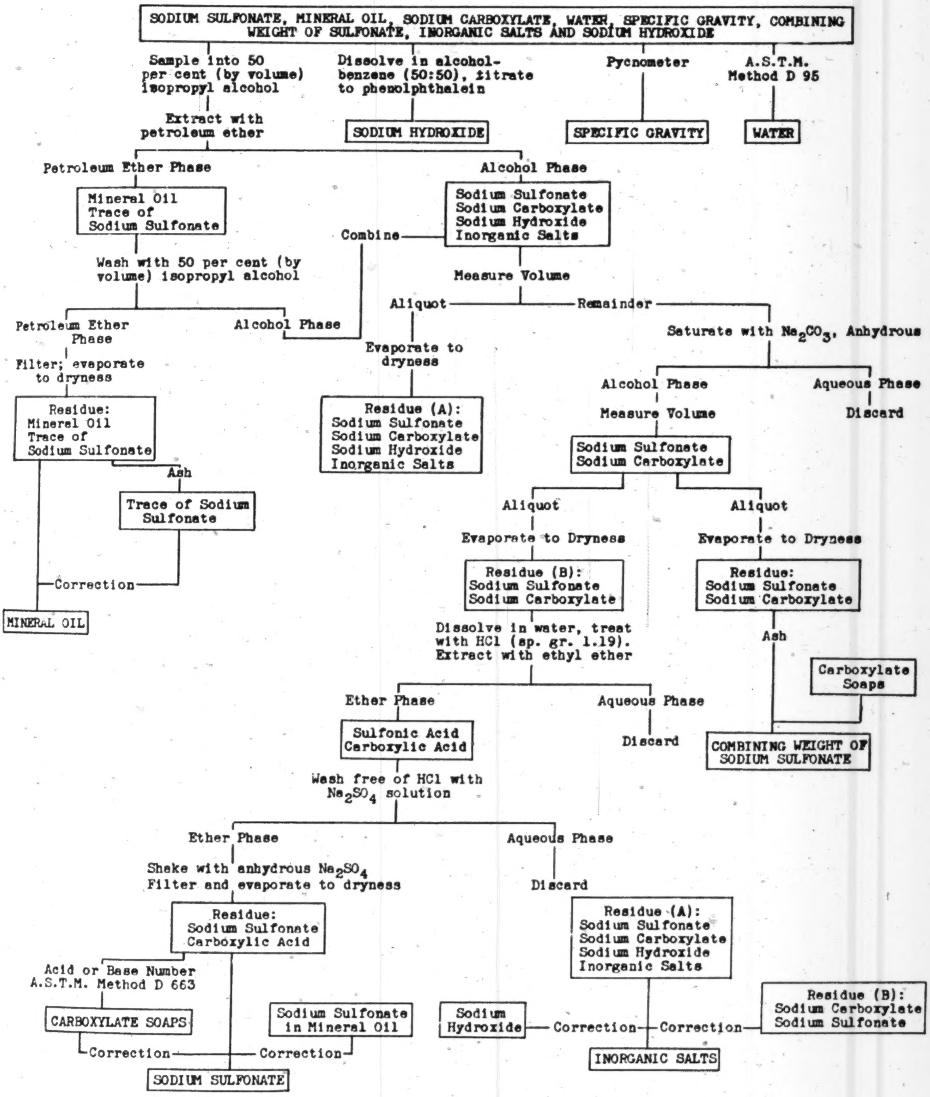

SODIUM SULFONATE, MINERAL OIL, SODIUM CARBOXYLATE, WATER, SPECIFIC GRAVITY, COMBINING WEIGHT OF SULFONATE, INORGANIC SALTS AND SODIUM HYDROXIDE
Sample into 50 per cent (by volume) isopropyl alcohol
Extract with petroleum ether
Dissolve in alcohol-benzene (50:50), titrate to phenolphthalein
SODIUM HYDROXIDE
Pycnometer
SPECIFIC GRAVITY
A.S.T.M. Method D 95
WATER
Petroleum Ether Phase
Mineral Oil Trace of Sodium Sulfonate
Wash with 50 per cent (by volume) isopropyl alcohol
Petroleum Ether Phase
Filter; evaporate to dryness
Residue: Mineral Oil Trace of Sodium Sulfonate
Ash
Trace of Sodium Sulfonate
Correction
MINERAL OIL
Alcohol Phase
Combine
Alcohol Phase
Sodium Sulfonate Sodium Carboxylate Sodium Hydroxide Inorganic Salts
Measure Volume
Aliquot
Remainder
Evaporate to dryness
Residue (A): Sodium Sulfonate Sodium Carboxylate Sodium Hydroxide Inorganic Salts
Saturate with Na2CO3, Anhydrous
Alcohol Phase
Measure Volume
Aqueous Phase
Discard
Sodium Sulfonate Sodium Carboxylate
Aliquot
Evaporate to Dryness
Residue (B): Sodium Sulfonate Sodium Carboxylate
Aliquot
Evaporate to Dryness
Residue: Sodium Sulfonate Sodium Carboxylate
Ash
Carboxylate Soaps
COMBINING WEIGHT OF SODIUM SULFONATE
Dissolve in water, treat with HCl (sp. gr. 1.19). Extract with ethyl ether
Ether Phase
Sulfonic Acid Carboxylic Acid
Aqueous Phase
Discard
Wash free of HCl with Na2SO4 solution
Ether Phase
Shake with anhydrous Na2SO4 Filter and evaporate to dryness
Residue: Sodium Sulfonate Carboxylic Acid
Acid or Base Number A.S.T.M. Method D 663
CARBOXYLATE SOAPS
Correction
Sodium Sulfonate in Mineral Oil
Correction
SODIUM SULFONATE
Aqueous Phase
Discard
Residue (A): Sodium Sulfonate Sodium Carboxylate Sodium Hydroxide Inorganic Salts
Sodium Hydroxide
Correction
Correction
Residue (B): Sodium Carboxylate Sodium Sulfonate
INORGANIC SALTS

FIG. 1.—Outline of Method of Analysis of Petroleum Sulfonates.

(*i*) *Acetone (c.p.).*

(*j*) *Benzene (c.p.).*

(*k*) *Ethyl Alcohol (95 per cent).*

(*l*) *Ethyl Ether.*

(*m*) *Isopropyl Alcohol (99, 91, and 50 per cent by volume).*

Mineral Oil

5. (*a*) Introduce approximately 10 g. of sample, W_1, weighed to the nearest centigram, into a tared 100-ml. beaker. Add 100 ml. of isopropyl alcohol (50 per

cent) and stir to dissolve the sodium sulfonate and disperse the oil; warm, if necessary, to hasten this process. Transfer quantitatively to a 500-ml. separatory funnel, rinsing the beaker and stirring rod with 25 ml. of isopropyl alcohol (50 per cent). Repeat rinsing of the beaker and stirring rod with 25 ml. of isopropyl alcohol (91 per cent). Add 20 ml. of distilled water to the separatory funnel.

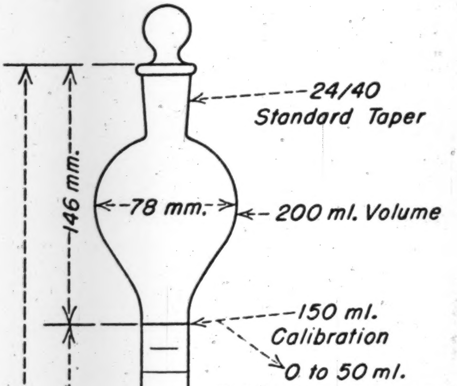

24/40 Standard Taper
78 mm.
200 ml. Volume
146 mm.
150 ml. Calibration
0 to 50 ml. Calibration Downward
28 mm.
136 mm.
480 mm.
100 ml. Calibration
60 mm.
100 ml. Volume
93 mm.
0 ml. Calibration (Completely Encircled)
104 mm.
25 mm.
3 mm. Bore

FIG. 2.—Desalting Funnel for Analysis of Petroleum Sulfonates.

NOTE.—It is important to adhere, as closely as possible, to the quantities and concentrations of isopropyl alcohol prescribed for rinsing the beaker and stirring rod. Final concentration in the separatory funnel should be not less than 48 nor more than 52 per cent by volume of isopropyl alcohol.

(*b*) Rinse the sampling beaker with 30 ml. of petroleum ether and use this portion of ether to extract the combined alcoholic solution; retain the interface "cuff" with the ether phase. Extract the alcoholic phase five more times with 30-ml. portions of petroleum ether, using two 250-ml. separatory funnels and collecting the petroleum ether extracts in the 500-ml. separatory funnel. Run the oil-free alcoholic sulfonate solution into the special desalting funnel. Rinse the 250-ml. separatory funnels with two 10-ml. portions of isopropyl alcohol (50 per cent) and add to the desalting funnel. Wash the combined ether extracts with 50 ml. of isopropyl alcohol (50 per cent); add the wash to the desalting funnel.

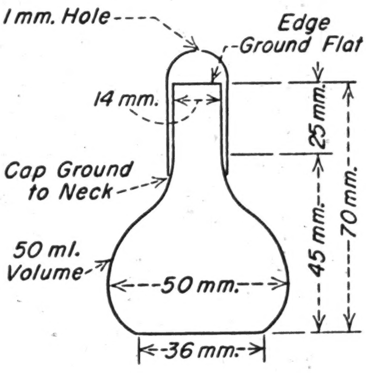

1 mm. Hole
Edge Ground Flat
14 mm.
25 mm.
Cap Ground to Neck
45 mm.
70 mm.
50 ml. Volume
50 mm.
36 mm.

FIG. 3.—Pycnometer for Determining Specific Gravity of Petroleum Sulfonates.

(*c*) Filter the combined ether extracts through a small plug of cotton, placed in the vortex of a filter funnel, into a tared, inverted-rim beaker. Wash the separatory funnel and filter with 20 to 30 ml. of fresh petroleum ether, adding the washings to the inverted-rim beaker. Evaporate the ether solution to dryness on a steam bath, heating for 15 min.

after the disappearance of the odor of petroleum ether or alcohol. Cool to room temperature and bring to constant weight in a vacuum desiccator at room temperature and under 3 mm. or less of mercury pressure, applying vacuum gradually and venting frequently to avoid spattering at the start. Denote the residue as R.

NOTE.—If it is known that a sample contains oil that is volatile under conditions of the test it may be preferred to subtract the total of other constituents from 100 per cent to obtain the mineral oil content.

(*d*) Weigh a 1 to 2-g. sample (r) of the oil residue from Paragraph (*c*) into a tared, ignited platinum crucible. Heat with a bunsen burner until the contents ignite and burn, then maintain at such a temperature that only ash and carbon remain after burning ceases. Ignite over a burner, or in a muffle furnace at 600 to 800 C., until the oxidation of carbon is complete. Cool and add 3 to 4 drops of H_2SO_4 (sp. gr. 1.84). Fume off the H_2SO_4 over a burner in a hood, but do not heat strongly enough to cause spitting. When fuming ceases, heat in a muffle furnace at 800 ± 50 C. to constant weight (A_1).

Oil-Free Total Solids

6. Read the total volume (V_1) of the oil-free alcohol solution, Section 5 (*b*), by inverting the stoppered desalting funnel; read the volume of liquid in the graduated tube and add it to that of the calibrated bulb. Pipette a 25-ml. aliquot into a tared 150-ml. beaker and evaporate to dryness on a steam bath, adding small portions of isopropyl alcohol (99 per cent) (or acetone) to aid in removing the water. Dry to constant weight (S_1) in a vacuum oven at 80 C. under less than 3 mm. of mercury pressure or in an atmospheric oven at 120 C. (The former usually requires from 1 to 2 hr., the latter from 4 to 8 hr.) When using the vacuum oven, apply the suction gradually at the start to avoid foaming. (The oil-free residue (S_1) consists of sulfonate, carboxylate, inorganic salts, and free alkali.)

Sulfonate

7. (*a*) Secure the stopcock of the desalting funnel with a suitable clamp and warm it in a water bath at 40 to 50 C. Weigh out 18 g. of anhydrous sodium carbonate per 100 ml. of alcohol solution remaining in the funnel. Carefully admit a few grains to the funnel, allowing the dissolved petroleum ether to evaporate slowly. When danger of boiling is past, add the remainder of the carbonate and shake the mixture vigorously. Allow the phases to separate; withdraw and discard the solid particles as soon as they settle to the bottom of the salt layer, swirling the solution to dislodge any solid particles clinging to the upper part of the funnel. Replace the funnel in the water at 40 to 50 C. until separation into two layers is complete; draw off the salt layer almost to the mark above the stopcock.

(*b*) Cool the funnel to room temperature (3 to 4 hr.). Draw off the lower layer so that the interface is at the mark. Read the volume (V_2) of the upper (alcohol) layer on the neck of the funnel; if the upper layer is cloudy, allow to stand overnight or filter through paper into a glass-stoppered Erlenmeyer flask.

(*c*) Pipette a 50-ml. aliquot of the clear alcohol layer into a tared 150-ml. beaker. Evaporate to dryness on a steam bath, adding small portions of isopropyl alcohol (or acetone) to aid in the removal of water. Dry to constant weight (S_2) in a vacuum oven at 80 C. under less than 3 mm. of mercury pressure, or in an atmospheric oven at 120 C. Denote the residue as S_2; save for carboxylate soap determination.

Carboxylate Soap

8. (*a*) Dissolve the residue (S_2) from Section 7 (*c*) in 200 ml. of water and transfer the solution quantitatively to a 500-ml. separatory funnel; wash out the beaker with two 25-ml. portions of water and add the washings to the separatory funnel. Add 50 ml. of 12 *N* HCl to the funnel and shake vigorously. Extract the liberated acids with two 100-ml. portions of ethyl ether. Combine the ether extracts. Wash the combined ether extracts free of HCl by shaking with two or more 50-ml. portions of sodium sulfate (20 per cent) containing methyl orange indicator. Discard the salt washings.

(*b*) Drain off as much water as possible from the washed ether extract. Lay the separatory funnel on its side and introduce about 10 g. of anhydrous sodium sulfate; make sure that the funnel mouth is free of sodium sulfate crystals before inserting the stopper. Shake the mixture vigorously for 3 or 4 min., venting frequently. Filter the ether solution, using a small plug of cotton in the vortex of a filter funnel, into a tared 250-ml. Erlenmeyer flask. Rinse the funnel and filter with 20 ml. of ethyl ether; add the rinsings to the main ether solution and evaporate the ether on a steam bath. Dry to constant weight in a shielded vacuum desiccator under less than 3 mm. of mercury pressure at room temperature.

(*c*) Determine the acid number on the residue from Paragraph (*b*) by A.S.T.M. Method D 663, Test for Acid and Base Numbers of Petroleum Products by Color-Indicator Titration.[2]

Inorganic Salts and Free Alkali

9. (*a*) *Inorganic Salts Plus Free Alkali.*—Calculate the inorganic salts plus free alkali content (Section 13(*e*)) from the data obtained in Sections 6 and 7 (*c*).

(*b*) *Free Alkali.*—Weigh approximately 10 g. of sample into a 250-ml. Erlenmeyer flask, add 50 ml. of ethyl alcohol and 50 ml. of benzene and swirl until dissolved. Add 4 or 5 drops of phenolphthalein indicator solution and titrate with standard 0.5 *N* H_2SO_4 to the end point.

Water

10. Determine the water content of the sample by A.S.T.M. Method D 95 or by the Karl Fischer Method.

Average Combining Weight of Sulfonate

11. (*a*) Pipette 25 ml. of the de-oiled and desalted alcoholic sulfonate solution (Section 7 (*b*)) into a tared, ignited, platinum crucible. Evaporate to dryness on a steam bath, adding small portions of isopropyl alcohol (or acetone) to aid in removal of water. Dry to constant weight (S_3) in a vacuum oven at 80 C. under less than 3 mm. of mercury pressure, or in an atmospheric oven at 120 C. (The drying to constant weight and the weighing on an analytical balance may be dispensed with if the value for S_3 is taken as half of S_2 (Section 7 (*c*)).

(*b*) Carefully heat the crucible over a small flame until the contents ignite; maintain the temperature so that the contents will burn gently. Ignite over a burner or in a muffle furnace at 600 to 800 C., cool, and add 3 or 4 drops each of 36 *N* H_2SO_4 and 16 *N* HNO_3. Heat carefully over a small flame until fuming ceases, taking care to not heat strongly enough to allow spitting. Repeat the treatment with HNO_3 alone until the ash is free of carbon (visual inspection). Cool, and add 3 or 4 drops of H_2SO_4 (sp. gr. 1.84). Fume off the acid, taking care to avoid spitting. When fuming ceases, heat in a muffle furnace at 800 ± 50 C. to constant weight (A_2).

Specific Gravity

12. Fill the pycnometer with the sample, warming to 70 to 80 C. in a closed vessel if necessary. If the sample was warmed, hold the pycnometer at 70 to 80 C. until all air bubbles have risen to the top. Place in a bath at 25 ± 0.2 C. for 2 hr. adding more sample if necessary so the pycnometer remains full. Remove excess product flush with the top of the pycnometer by means of a spatula. Remove the pycnometer from the bath, wipe the sides of the neck with a cloth moistened with alcohol, wipe dry and adjust the cap into place. Thoroughly dry the outside of the pycnometer and weigh to the nearest 1 mg. Record the sample weight as W_s.

Calculations

13. (*a*) *Mineral Oil Content.*—Calculate the mineral oil content of the sample as follows:

Mineral oil content, per cent =

$$\frac{100R}{W_1} - \frac{200A_1RC}{142.1rW_1}$$

where:

W_1 = weight of sample in grams (Section 5 (*a*)),

R = weight of oil residue in grams (Section 5 (*c*)),

r = weight of oil residue taken for ashing in grams (Section 5 (*d*)),

A_1 = weight of sodium sulfate ash from oil residue in grams (Section 5 (*d*)), and

C = combining weight of sulfonate (if not determined, assume 465 for the sodium salt.)

(*b*) *Oil-Free Total Solids.*—Calculate the oil-free total solids of the sample as follows:

$$\text{Total oil-free solids, } J, \text{ per cent} = \frac{4S_1V_1}{W_1}$$

where:

S_1 = weight of oil-free residue in grams (Section 6),

V_1 = volume of alcoholic sulfonate solution in milliliters (Section 6), and

W_1 = weight of sample in grams (Section 5 (*a*)).

(*c*) *Oil-Free, Salt-Free Soaps, and Sodium Sulfonate Content.*—Calculate the oil-free soap and sodium sulfonate content as follows:

Oil-free, salt-free soap content, K,

$$\text{per cent} = \frac{2S_2V_2V_1}{(V_1 - 25)W_1}$$

Sodium sulfonate content, per cent =

$$K + \frac{200A_1RC}{142.1rW_1} - D$$

where:

S_2 = weight of sulfonate and carboxylate soaps in grams (Section 7 (*c*)),

V_2 = volume of dehydrated alcohol layer in milliliters (Section 7 (*b*)),

V_1 = volume of alcoholic sulfonate solution in milliliters (Section 6),

W_1 = weight of sample in grams (Section 5 (*a*)),

R = weight of oil residue in grams (Section 5 (*c*)),

r = weight of oil residue taken for ashing in grams (Section 5 (*d*)),

A_1 = weight of sodium sulfate ash from oil residue in grams (Section 5 (*d*)),

C = combining weight of sulfonate (if not determined, assume 465 for the sodium salt), and

D = percentage of sodium carboxylate content of sample (Paragraph (*d*)).

NOTE.—If the sample contains the potassium or ammonium salt or sulfonic acid and the combining weight is not determined, assume 481 for the potassium salt and 460 for the ammonium salt.

(*d*) *Carboxylate Soap.*—Calculate the carboxylate soap content of the sample as follows:

$$\text{Carboxylate soap content, } D\text{, per cent} = \frac{1.07BK}{180}$$

where:

B = acid number of residue (Section 8 (*c*)) expressed as milligrams of KOH per gram, and

K = percentage of oil-free, salt-free soap content (Paragraph (*c*)).

(*e*) *Inorganic Salts and Free Alkali.*—Calculate the inorganic salts, plus free alkali content as follows:

$$\text{Inorganic salts plus free alkali, } L\text{, per cent} = J - K$$

where:

J = percentage of total oil-free solids (Paragraph (*b*)), and

K = percentage of oil-free, salt-free soap content (Paragraph (*c*)).

$$\text{Free alkalinity as NaOH, } M\text{, per cent} = \frac{4VN}{W_2}$$

where:

V = volume of sulfuric acid consumed in milliliters,

N = normality of sulfuric acid, and

W_2 = weight of sample in grams (Section 9 (*b*)).

$$\text{Inorganic salts, per cent} = L - M$$

where:

L = percentage of inorganic salts plus free alkali, and

M = percentage of free alkalinity as NaOH.

(*f*) *Average combining weight of sulfonate.*—Calculate the carboxylate soap correction for the purified sulfonate as follows:

$$\text{Sodium sulfate equivalence of carboxylate soap, } G\text{, per cent} = 0.127B$$

where:

B = acid number of residue (Section 8 (*b*)).

Calculate the ash on the de-oiled, desalted soaps (Section 8 (*c*)) as follows:

$$\text{Ash, } F\text{, per cent} = \frac{100A_2}{S_3}$$

where:

A_2 = ash on de-oiled, desalted soap solution in grams (Section 11 (*b*)), and

S_3 = weight in grams of dry de-oiled, desalted soaps (Section 11 (*a*) or one-half the value S_2 (Section 7 (*c*)).

Calculate the combining weight of the sodium sulfonate as follows:

$$\text{Combining weight of sodium sulfonate} = \frac{7100}{F - G}$$

where:

F = percentage of ash on the de-oiled, desalted soaps, and

G = percentage of sodium sulfate equivalence of carboxylate soaps.

(*g*) *Specific Gravity.*—Calculate the specific gravity as follows:

$$\text{Specific gravity, 25/25 C.} = \frac{W_s}{W_c}$$

where:

W_s = weight in grams of sample contained by pycnometer at 25 C., and

W_c = weight in grams of water contained by pycnometer at 25 C. (Section 3 (*k*)).

APPENDIX IV

PROPOSED METHOD OF TEST FOR POTENTIAL GUM IN AVIATION GASOLINE[1]

This is a proposed method and is published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 260 S. Broad St., Philadelphia 2, Pa.

1. *Scope.*—This method covers a procedure for an accelerated oxidation stability test for aviation gasoline by means of which the quantity of residue (gum plus lead deposit) is measured after the gasoline has been oxidized for a specified time under prescribed conditions.

2. *Apparatus:* (*a*) *Bomb.*—The bomb shall be made of a stainless steel (Note 1) with the inside dimensions of the portion that encloses the reacting gasoline-oxygen mixture conforming substantially to those shown in Fig. 1. The interior surface of the bomb and lid shall be given a high polish to facilitate cleaning and to prevent corrosion. Other structural details such as the method of closure, gasket material, and outside dimensions are optional, provided the following limitations are observed:

(*1*) The bomb shall be constructed to withstand a working pressure of 180 psi. at 212 F. (100 C.), with an ultimate strength at least equal to that of a bomb constructed of 18 per cent chromium, 8 per cent nickel alloy steel (Note 1) and having dimensions as shown in Fig. 1.

(*2*) The closure (Note 2) shall be capable of making a seal that will not leak when the bomb is filled with oxygen to 100 psi. at 60 to 80 F. (15.6 to 26.7 C.), and plunged into a bath at 212 F. (100 C.). Any suitable gasket material may be used that will not react with oxygen (Note 3).

(*3*) The weight of the bomb assembled as shown in Fig. 1, but without the oxygen valve and glass liner, shall be not less than 5.0 lb. nor more than 8.0 lb. This weight shall be distributed about the sample container in a manner equivalent to that shown in Fig. 1.

Note 1.—A suitable material is an 18 per cent chromium, 8 per cent nickel alloy steel conforming to grade S, type 304, of the Standard Specifications for Corrosion-Resisting Chromium and Chromium-Nickel Steel Sheet, Strip, and Plate for Fusion-Welded Unfired Pressure Vessels (A.S.T.M. Designation: A 240) of the American Society for Testing Materials;[2] or S.A.E. Nos. 30905 or 30915.[3]

Note 2.—It is preferable that the closure ring be constructed from an alloy different from that used for the bomb body, particularly if the bomb metal is that specified in Note 1 and if the mating threads of the two parts are to move with respect to each other when a tightening load is applied.

Note 3.—Reactivity with oxygen shall be determined by the following test: The gasket under test shall be placed in the bomb in the absence of gasoline and a gasket of similar composition used in the attachment of the cover. The bomb shall be filled with oxygen to a pressure of 100 psi. and immersed in a bath at about 212 F. (100 C.). If the pressure does not drop more than 2 lb. from the maximum in a 24-hr. period, with the bath temperature differing by not more than 2.0 F. from that when the pressure was at its maximum, the gasket shall be considered nonreactive in the presence of oxygen.

(*b*) *Glass Liner.*—A glass liner for the bomb shall be provided, the shape and

---

[1] This proposed method is under the jurisdiction of the A.S.T.M. Committee D-2 on Petroleum Products and Lubricants. Published as information, June, 1941; modified June, 1942, June, 1944.

[2] 1944 Book of A.S.T.M. Standards, Part I.

[3] 1944 S.A.E. Handbook, p. 307.

dimensions of which shall conform to those shown in Fig. 1. The glass liner shall fit snugly inside the bomb.

(*c*) *Bomb Accessories.*—The bomb lid shall be provided with a stem and stem filler rod, both constructed of stainless steel and having dimensions substantially as shown in Fig. 1. The inside of the stem and the outside of the filler rod shall be given a high polish to facilitate cleaning. Means shall be provided for connecting to the bomb stem an indicating or recording pressure gage (Paragraph (*d*)) and a tightly closing needle valve (Note 4) through which oxygen may be admitted. The connection to the source of oxygen may be made as indicated in Fig. 1, or it may be made through a tee or cross connection on the top of the bomb stem. A circular metal plate of a diameter sufficient to serve as a lid for closing the bath when the bomb is in place shall be fitted to the stem in any convenient manner but in the position shown in Fig. 1. A suitable holder for the bomb and an adequate wrench for obtaining a tight closure shall be provided.

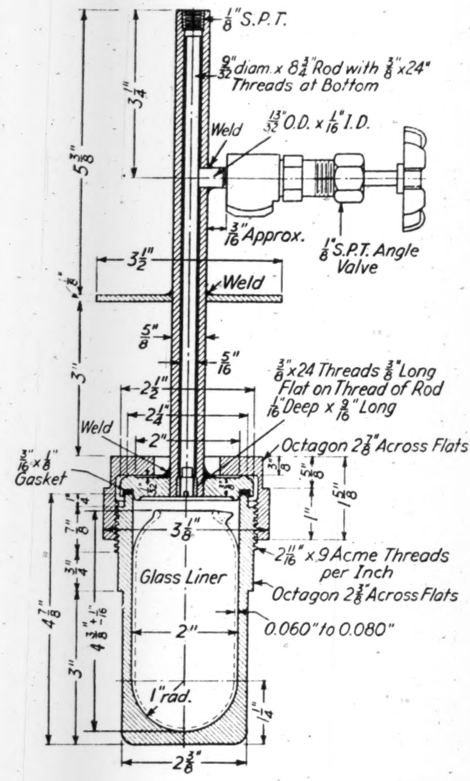

1/8" S.P.T.
9/32" diam. x 8 3/4" Rod with 3/8" x 24" Threads at Bottom
Weld
13/32" O.D. x 1/16" I.D.
3 1/4"
5 3/8"
3/16" Approx.
1/8" S.P.T. Angle Valve
3 1/2"
1/8"
Weld
5/8"
5/16"
3"
3/8" x 24 Threads 3/8" Long
Flat on Thread of Rod 1/16" Deep x 9/16" Long
2 1/2"
2 1/4"
Weld
2"
Octagon 2 7/8" Across Flats
3/16" x 1/8" Gasket
3/8"
5/8"
1 5/8"
1"
1/32
1/8
1/4"
7/8"
3 1/8"
3/4"
2 11/16" x 9 Acme Threads per Inch
Glass Liner
Octagon 2 3/8" Across Flats
4 7/8"
4 3/8" +/- 1/16"
2"
0.060" to 0.080"
3"
1" rad.
1 1/4"
2 3/8"

FIG. 1.—Bomb for Accelerated Oxidation.

NOTE 4.—For convenience in handling, it is suggested that a tire valve and stem be attached to a three-way pressure cock which in turn is attached to the needle valve and that the oxygen be introduced through a suitable high-pressure air hose and fitting. It is considered safer practice to release the gas in the bomb through the third unobstructed port of the three-way cock rather than through the small orifice of the tire valve. The needle valve must not be eliminated, as it is necessary to insure against leaks at this point during the test.

(*d*) *Pressure Gage.*—A pressure gage with a maximum reading of 200 psi. shall be used. It may be of either the indicating or the recording type. The scale for the range 100 to 180 psi. shall average at least 1 in. per 50 psi. pressure differential measured along the arc of the scale. Intervals of division shall be 5 psi. or less. The accuracy shall be 1 per cent of the total scale interval. The gage may be connected to the bomb stem directly or by a flexible metal tubing, but the total volume of the stem with filler rod in place and all connections shall be not more than 15 ml.

(*e*) *Oxidation Bath.*—The oxidation bath shall be a water bath having a capacity of not less than 4.5 gal. per bomb, and of such dimensions that the maintained depth of liquid is not less than 11.5 in. The bath **shall be equipped with a condenser and a heating unit for keeping the water boiling continuously. It also shall have a thermometer well such that the 206 F. (96.7 C.) point of the thermometer (Paragraph (*f*)) shall be of the same level as the upper surface of the bath cover. A round opening of such a diameter as to accommodate the bomb and to fit the plate fastened to the bomb stem shall be provided. The top of the bomb lid shall be submerged at least 2 in. below the surface of the bath liquid.**

(*f*) *Thermometer.*—The thermometer shall be an A.S.T.M. Saybolt Viscosity Thermometer, graduated in either Fahrenheit or Centigrade degrees as specified, having a range of 204 to 218 F. or 95 to 103 C. and conform-

ing to the requirements for this thermometer as prescribed in the Standard Specifications for A.S.T.M. Thermometers (A.S.T.M. Designation: E 1) of the American Society for Testing Materials.[4]

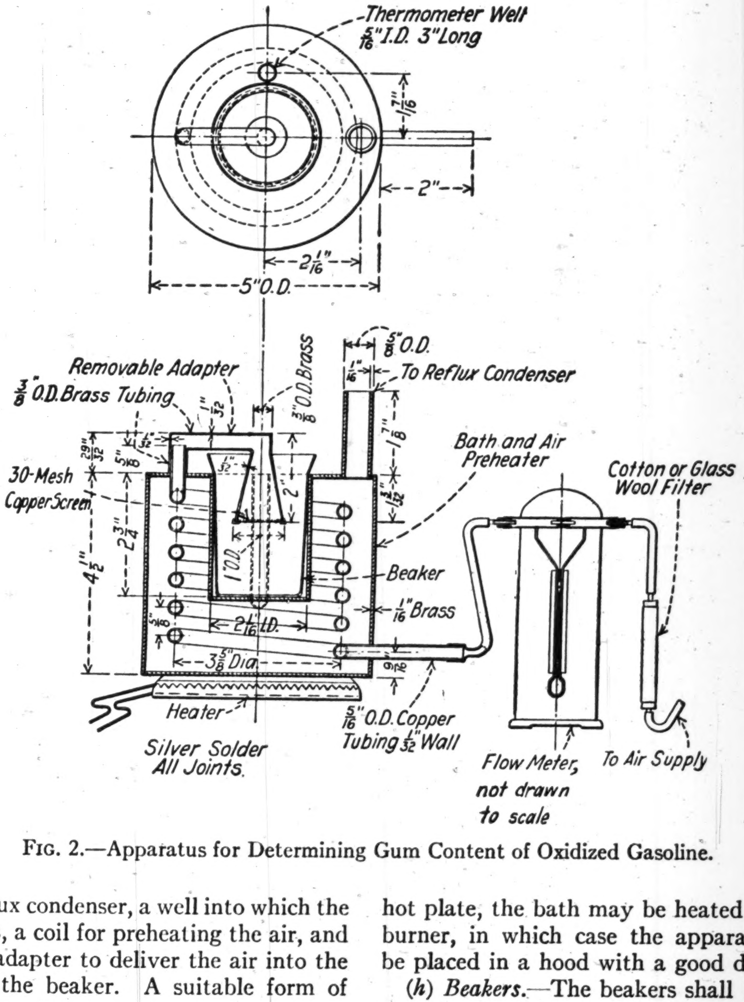

Thermometer Well
$\frac{5}{16}$" I.D. 3" Long
$\frac{7}{16}$"
2"
$2\frac{1}{16}$"
5" O.D.
Removable Adapter
$\frac{3}{8}$" O.D. Brass Tubing
$\frac{1}{32}$"
$\frac{3}{8}$" O.D. Brass
$\frac{5}{8}$" O.D.
$\frac{1}{16}$"
To Reflux Condenser
$1\frac{7}{8}$"
$1\frac{3}{32}$"
$\frac{29}{32}$"
$\frac{5}{8}$"
30-Mesh Copper Screen
$2\frac{3}{4}$"
$4\frac{1}{2}$"
2"
1" O.D.
Bath and Air Preheater
Cotton or Glass Wool Filter
Beaker
$\frac{1}{16}$" Brass
$2\frac{1}{16}$ I.D.
$\frac{5}{8}$"
$3\frac{5}{8}$" Dia.
$\frac{9}{16}$"
Heater
$\frac{5}{16}$" O.D. Copper Tubing $\frac{1}{32}$" Wall
Silver Solder All Joints.
Flow Meter, not drawn to scale
To Air Supply

FIG. 2.—Apparatus for Determining Gum Content of Oxidized Gasoline.

(*g*) *Evaporation Bath.*—The evaporation bath shall consist of a closed vessel provided with a reflux condenser, a well into which the beaker fits, a coil for preheating the air, and a conical adapter to deliver the air into the center of the beaker. A suitable form of apparatus is shown in Fig. 2. A multiple bath having similar provisions is also satisfactory. The bath shall be filled to within 1 in. of the top with a stable liquid having a boiling point within a temperature range from 320 to 330 F. (160 to 165.8 C.). Ethylene glycol containing approximately 3 per cent water is suitable for the purpose. The bath shall be insulated with asbestos. An electric hot plate capable of keeping the liquid boiling actively is the preferred heating means. In the absence of a satisfactory hot plate, the bath may be heated by a gas burner, in which case the apparatus shall be placed in a hood with a good draft.

(*h*) *Beakers.*—The beakers shall be of the Berzelius type, made of heat-resistant glass, without lip, and of 100-ml. nominal capacity.

(*i*) *Gooch Crucible.*—A sintered-glass Gooch crucible, fine porosity, of 25-ml. nominal capacity shall be used.

(*j*) *Air Supply.*—Low-pressure air shall be passed through a cotton or glass-wool filter and delivered to the preheater inlet of the bath. A flowmeter or other air-measuring device shall be provided as shown in Fig. 2. The flowmeter shall be calibrated when attached to the bath with the bath liquid at room temperature.

---

[4] 1944 Book of A.S.T.M. Standards, Part III.

3. *Procedure.*—(*a*) Carefully clean the bomb and its accessories before starting the test. Wash the glass liner with a suitable gum solvent (Note 5) and allow to dry. Soak the liner for a minimum of 12 hr. in chromic acid solution, rinse at least three times with distilled water, and finally dry by heating in an oven. The glass liner should be handled only with clean metal forceps after cleaning. Drain from the bomb any gasoline present and wipe the inside of the bomb and cap, first with a clean cloth moistened with the gum solvent and then with a clean dry cloth. Remove the gum or gasoline in the annular space with gum solvent. Occasionally remove the filler rod from the stem and carefully clean both stem and rod. The annular space shall be thoroughly dry before each test is started.

NOTE 5.—Either acetone or a blend of benzol and ethyl alcohol (1:1) is a satisfactory gum solvent.

(*b*) Bring the bomb and the gasoline to be tested to a temperature of 60 to 80 F. (15.6 to 26.7 C.). Place the glass liner in the bomb and add 100 ± 1 ml. of sample. Close the bomb and introduce oxygen until a pressure of about 100 psi. is obtained. Allow the gas in the bomb to escape slowly in order to flush out the air originally present. Introduce oxygen again until a pressure of about 100 to 102 psi. is obtained, and then observe for leaks (Note 6). If there are no leaks, the test may be continued.

NOTE 6.—An initial rapid drop in pressure, generally not over 6 psi. may be observed because of the solution of oxygen in the sample. If after a few minutes the rate of pressure drop does not exceed 1 psi. in 10 min., the absence of leaks may be assumed.

(*c*) Place the charged bomb in the bath of vigorously boiling water, being careful to avoid shaking, and record the time of immersion as the starting time. Maintain the temperature of the water at 212 ± 0.2 F. (100 ± 0.11 C.). Leave the bomb in the oxidation bath for the specified time. (Note 7). If the atmospheric pressure is such that the temperature of boiling water is not within the specified range of 212 ± 0.2 F. (100 ± 0.11 C.) but is or can be made to fall within the range of 209 to 215 F. (98.3 to 101.7 C.), increase or decrease the time of heating in accordance with the schedule given in Table I.

TABLE I.—TEMPERATURE CORRECTION FACTORS.[a]

Temperature		Correction Factor
deg Cent.	deg. Fahr.	
98.4	209.1	1.158
98.6	209.5	1.137
98.8	209.8	1.116
99.0	210.2	1.096
99.2	210.6	1.075
99.4	210.9	1.056
99.6	211.3	1.037
99.8	211.6	1.019
100.0	212.0	1.000
100.2	212.4	0.982
100.4	212.7	0.964
100.6	213.1	0.947
100.8	213.4	0.930
101.0	213.8	0.914
101.2	214.2	0.897
101.4	214.5	0.881
101.6	214.9	0.865

[a] To obtain the correct aging time at the desired operating temperature multiply the specified time at 212 F. (100 C.) by the factor given.

NOTE 7.—If, as indicated by a steady drop in pressure, a leak develops after the bomb is placed in the bath, the test shall be discarded.

(*d*) At the completion of the oxidation period, remove the bomb from the bath and cool rapidly with water while the charging valve is still closed. Release the pressure slowly, take the bomb apart, and remove the glass liner.

(*e*) Filter the oxidized gasoline through a clean, dried, weighed Gooch crucible and save the filtrate. Wash the interior of the liner twice with fresh 10-ml. portions of solvent (Note 5) to remove any insoluble gum or visible lead precipitate. Filter the washings through the crucible and add the filtrate to the filtered oxidized sample. To insure homogeneity, mix the combined filtrates thoroughly and reserve for the gum determination (Paragraph (*g*)). Wash any visible precipitate remaining in the glass liner with additional solvent. Collect the precipitate in the crucible, but discard the wash liquid. Dry the crucible at 302 F.

(150 C.) in an oven for 1 hr., cool in a covered vessel, and weigh. Record any increase in weight greater than 0.2 mg. as *visible lead precipitate.*

NOTE 8.—Avoid exposing the sample to daylight prior to and during this test. At the end of the test no visible precipitate shall be present in the glass liner.

(*f*) Wash two test beakers, and a similar tare beaker, free from gum with the solvent (Note 5), immerse for at least 12 hr. in chromic-acid cleaning solution, and wash thoroughly, first with tap water and then with distilled water. Subsequent to removal from the cleaning solution, handle the beakers only by means of clean metal forceps. After washing, thoroughly dry all three beakers by heating to about 302 F. (150 C.), and allow to cool simultaneously for the same period of time, but not less than 1 hr., in a covered vessel (Note 9). Weigh each test beaker, using the tare (Note 10) on the opposite balance pan. After weighing, replace the tare beaker in the covered vessel and place the test beakers in the wells of the bath as shown in Fig. 2. Adjust the air flow to a rate, at the point of measurement, of 1 liter per sec. ±15 per cent. Heat the bath so that the temperature of the effluent air, measured by a thermometer placed on the bottom of the beaker at the center, is from 305 to 320 F. (151.7 to 160 C.). This is governed largely by the rate of boiling of the bath liquid and the rate of air flow.

NOTE 9.—The use of drying agents in the covered vessel and in the balance case is not recommended.

NOTE 10.—For routine tests it is permissible to use the same beaker as a tare for more than one test beaker but not for more than six test beakers, provided all are heated at the same time.

(*g*) Remove the conical adapters and pour approximately one half (plus or minus 2 ml.) of the reserved filtrate (Paragraph (*e*)) into each beaker; then replace the adapters on the air outlet so that they are vertically above the center of the surface of the liquid. After the liquid has evaporated, which should require from 5 to 10 min., leave the beakers in place for an additional 15 min., the air supply being maintained. During this 15-min. period, heat the tare beaker to about 302 F. (150 C.). Allow both test and tare beakers to cool simultaneously for the same period of time, but not less than 1 hr., in a covered vessel under the same conditions as prescribed in Paragraph (*f*). Weigh the two test beakers as before the test (Note 10). Record in milligrams the sum of the increase in weight of the beakers.

4. *Report.*—Report the value recorded in Section 3 (*g*) as potential gum per 100 ml. of sample. Report the sum of the potential gum and visible lead precipitate (Section 3 (*e*)) as total residue per 100 ml. of sample.

REPORT OF SECTIONAL COMMITTEE Z11

ON

PETROLEUM PRODUCTS AND LUBRICANTS

ASA PROJECT: Z11

Sectional Committee Z11 on Petroleum Products and Lubricants held one meeting during the year: in Pittsburgh, Pa., on June 29, 1943.

During the past year, the American Standards Association, on the recommendation of the sectional committee, reapproved two American Standards in which revisions have been made, and likewise approved three A.S.T.M. standards as American Standard for the first time, assigning the following ASA designations:

Test for Vapor Pressure of Petroleum Products (Reid Method) (D 323 - 43; ASA Z11.44),
Test for Carbonizable Substances in White Mineral Oil (Liquid Petrolatum) (D 565 - 43; Z11.49—1943),
Test for Dropping Point of Lubricating Grease (D 566 - 42; Z11.51—1943),
Test for Carbonizable Substances in Paraffin Wax (D 612 - 43; Z11.50—1943), and
Standard Viscosity-Temperature Charts for Liquid Petroleum Products (D 341 - 43; Z11.39—1943).

At a meeting held during the 1944 Annual Meeting of the A.S.T.M., the following four tentative standards were recommended by Committee D-2 on Petroleum Products and Lubricants for reference to letter ballot of the Society for adoption as standard. The sectional committee voted to recommend to the American Standards Association the approval of these methods as American Standard upon their adoption as A.S.T.M. standards:

Test for Oil Content of Paraffin Wax (D 721 - 43 T),
Test for Knock Characteristics of Motor Fuels (D 357 - 43 T),
Test for Saponification Number of Petroleum Products (D 94 - 43 T), as revised, and
Conversion of Kinematic Viscosity to Saybolt Furol Viscosity (D 666 - 42 T).

These four recommendations will accordingly be referred to letter ballot in the sectional committee.

Since the standards listed below, already having ASA approval, have been revised this year, Committee D-2 has recommended that they be presented to the ASA in their revised form for reapproval as American Standard:

Revision of A.S.T.M. Standard Methods of:

Test for Gum Content of Gasoline (D 381 - 42; Z11.36—1942),
Test for Sulfur in Petroleum Oils by Bomb Method (D 129 - 39; Z11.13—1939), and
Test for Viscosity by Means of the Saybolt Viscosimeter (D 88 - 38; Z11.2—1938).

The sectional committee voted to refer these revisions to the ASA subject to approval by letter ballot.

The election of officers and other members of the Executive Committee of Sectional Committee Z11 for the ensuing term of two years resulted in the selection of the following:

Chairman, T. A. Boyd.

Vice-Chairman, T. G. Delbridge.

Other members of Executive Committee:

R. P. Anderson,	A. J. Kraemer,
A. L. Beall,	K. G. Mackenzie, and
H. C. Dickinson,	J. B. Rather.

Respectfully submitted on behalf of the sectional committee,

T. A. BOYD,
Chairman.

R. E. HESS,
Secretary.

REPORT OF COMMITTEE D-3
ON
GASEOUS FUELS

A joint meeting of Committee D-3 on Gaseous Fuels and its seven subcommittees was held on October 24, 1943, in St. Louis, Mo.

Reports were presented at this meeting by subcommittee chairmen covering the activities of their groups during the preceding year. In spite of the increasing amount of attention which many of the members are giving to war projects, considerable progress has been made in the committee work. Steps have also been taken looking toward the distribution of further information developed from previous studies so that it could be made more generally available.

Brief accounts of the activities of the various subcommittees for the past year are given below:

Subcommittee I on Collection of Gaseous Samples (S. J. Modzikowski, chairman).—The work of this group is in process of reorganization. It is planned to prepare individual methods for sampling of natural, manufactured, and liquefied petroleum gases These methods will be published individually as soon as they are completed.

Subcommittee II on Measurement of Gaseous Samples (H. S. Bean, chairman).—A patent was granted during the year covering an attachment to wet gas meters, based on work previously performed for this group. The purpose of this attachment is to maintain constant the volume discharged per revolution of the drum regardless of the flow rate within the capacity range of the meter.

Subcommittee III on Determination of Calorific Value of Gaseous Fuels (R. B. Harper, chairman).—Work is now practically completed on the assembly of established data, formulas, charts, diagrams, procedures, etc., into a proposed tentative method for the determination of the calorific value of industrial gaseous fuels. It is expected that the method will be referred to letter ballot vote in the subcommittee in the fall of 1944.

Subcommittee IV on Determination of Specific Gravity and Density of Gaseous Fuels (E. F. Schmidt, chairman).—At the request of the chairman, an abstract was prepared of the "Report on Tests of Instruments for the Determination, Indication, or Recording of the Specific Gravities of Gases," issued in mimeographed form by the National Bureau of Standards. This report is quite voluminous, consisting of 240 pages with numerous illustrations, graphs, and tables. Only limited distribution was possible at the time but on account of the value of the information presented, it was felt highly desirable that attention of those interested in specific gravity measurement should be directed to the availability of this report. Therefore, at the request of the subcommittee, an article was prepared for publication by the secretary of Committee D-3 entitled "Instruments for Determination of Specific Gravity of Gases." Reprints are expected to be available shortly.

Consideration is now being given to publication of the complete report. It is hoped that it will be available at a later date.

Subcommittee V on Determination of Special Constituents of Gaseous Fuels (E. F. Pohlmann, chairman).—Consideration is being given to the development of methods for determination of sulfur. An investigation is in progress at the Institute of Gas Technology in Chicago to determine the identity and proportions of specific sulfur compounds in gaseous fuels.

Analytical methods are being prepared which cover determination of total organic sulfur, carbon disulfide, carbon oxysulfide, mercaptans, and thiophenes.

Subcommittee VI on Determination of Water Vapor Content of Gaseous Fuels (A. W. Gauger, chairman).—A revised procedure for calorimetric determination of water vapor in gaseous fuels has been worked out and prepared by R. J. Pfister and D. J. Kerley. In addition to distribution in the committee for comment, it has been published in the ASTM BULLETIN.[1]

E. R. Weaver of the National Bureau of Standards has submitted to the chairman a new procedure for the determination of water vapor in oxygen. This procedure, which is based on the conductivity of a film, will be tested in The Pennsylvania State College Laboratories on Gaseous Fuels.

Subcommittee VII on Complete Analysis or Chemical Composition of Gaseous Fuels (Martin Shepherd, chairman).—Steps are now being taken looking toward the publication of the results of the coöperative analysis of standard gas samples conducted by the subcommittee and assisting laboratories. The first part of this report is expected to be available during the summer and the second part before the end of the year. Additional analyses are now under way so that results can be included in this report when issued.

The present officers of the committee have been re-elected for the ensuing term of two years.

This report has been submitted to letter ballot of the committee which consists of 33 members; 28 members returned their ballots; all of whom voted affirmatively.

Respectfully submitted on behalf of the committee,

A. W. GAUGER,
Chairman

R. M. CONNER,
Secretary.

---

[1] R. J. Pfister and D. J. Kerley, "A Colorimetric Method for Determining the Water Vapor Content in Fuel Gases, Utilizing the Evelyn Colorimeter," ASTM BULLETIN, No. 127, March, 1944, p. 17.

REPORT OF COMMITTEE D-4

ON

ROAD AND PAVING MATERIALS

Committee D-4 on Road and Paving Materials has held two meetings during the past year: in Pittsburgh, Pa., on June 28, 1943, and in Cincinnati, Ohio, on February 29, 1944.

Subsequent to the 1943 Annual Meeting, Committee D-4 presented to the Society through Committee E-10 on Standards, the following recommendations:

Tentative Revisions of Standards:

Specifications for Preformed Expansion Joint Fillers for Concrete (Nonextruding and Resilient Types) (D 544 – 41),

Methods of Testing Preformed Expansion Joint Fillers for Concrete (Nonextruding and Resilient Types) (D 545 – 41), and

Revision of Tentative Standard:

Specifications for Tar (D 490 – 43 T).

The tentative revisions were accepted[1] by Committee E-10 on November 4, 1943, and the revised tentative standard was accepted[1] on November 10, 1943. All three recommendations appear in the 1943 Supplement to Book of A.S.T.M. Standards, Part II.

I. NEW TENTATIVE STANDARD

Committee D-4 recommends that the Method of Test for Hot Extraction of Asphaltic Materials and Recovery of Bitumen by the Modified Abson Procedure,[2] developed by Subcommittee B-6 on Extraction and Recovery of Constituents from Bituminous Mixtures (R. R. Thurston, chairman), be accepted for publication as tentative. This method is the result of a large volume of cooperative work on the part of the members of the subcommittee, the results of which are shown in Tables I and II.

II. ADOPTION AS STANDARD OF TENTATIVE REVISIONS OF STANDARDS

The committee recommends that the tentative revision[3] of the Standard Method of Test for Ductility of Bituminous Materials (D 113 – 39), submitted August, 1941, be approved for reference to letter ballot of the Society for adoption as standard.

Committee D-4 joins with Committee C-9 on Concrete and Concrete Aggregates in recommending incorporation in the present Standard Method of Test for Abrasion of Coarse Aggregate by Use of the Los Angeles Machine (C 131 – 39), the tentative revisions which were submitted in June, 1941, and which appear on page 1441 of Part II of the 1942 Book of A.S.T.M. Standards. Recommendation for the advancement of these tentative revisions to standard has not been made previously because

---

[1] In submitting these recommendations to Committee E-10 on Standards, Committee D-4 reported the following results of the letter ballot vote from a committee membership of 128: D 544, affirmative 49, negative 6, ballots marked "not voting" 14; D 545, affirmative 53, negative 2, ballots marked "not voting" 14; D 490, affirmative 51, negative 1, ballots marked "not voting" 17.

[2] This method was accepted as tentative by the Society and appears in the 1944 Book of A.S.T.M. Standards, Part II, p. 1386.

[3] 1943 Supplement to Book of A.S.T.M. Standards, Part II, p. 163.

TABLE I.—COOPERATIVE WORK ON RECOVERY OF ASPHALT BY MODIFIED ABSON METHOD.

	The Texas Co.		Chicago Testing Laboratory		Standard Oil Co. of Indiana		Wisconsin State Highway Dept.		Arizona State Highway Dept.		Virginia State Highway Dept.		New Jersey State Highway Dept.		A. W. Dow, Inc.		Michigan State Highway Dept.	
	Paving Asphalt 125 to 145 Penetration	Oxidized Asphalt 25 to 30 Penetration	Paving Asphalt 125 to 145 Penetration	Oxidized Asphalt 25 to 30 Penetration	Paving Asphalt 125 to 145 Penetration	Oxidized Asphalt 25 to 30 Penetration	Paving Asphalt 125 to 145 Penetration	Oxidized Asphalt 25 to 30 Penetration	Paving Asphalt 125 to 145 Penetration	Oxidized Asphalt 25 to 30 Penetration	Paving Asphalt 125 to 145 Penetration	Oxidized Asphalt 25 to 30 Penetration	Paving Asphalt 125 to 145 Penetration	Oxidized Asphalt 25 to 30 Penetration	Paving Asphalt 125 to 145 Penetration	Oxidized Asphalt 25 to 30 Penetration	Paving Asphalt 125 to 145 Penetration	Oxidized Asphalt 25 to 30 Penetration
Original Tests:																		
Softening Point, deg. F. (A.S.T.M. D 36)[a]	112	145	111	146	109.5	144	110.8	146.5	113	148.3	109.4	145.4	109	146.8	110.6	143.6	112	147
Ductility at 25 C. (77 F.), (5 cm. per min.), cm. (A.S.T.M. D 113)[b]	150+	10.5	130+	10.5	140+	10.5	110+	10.5	100+	8	110+	11	136	10	100+	11	115	15
Penetration (A.S.T.M. D 5):[c]																		
0 C. (32 F.), 200 g., 1 min.	35	13	37	13	37	12	37	14	41	13	41	12	38	12	38	13	45	15
25 C. (77 F.), 100 g., 5 sec.	134	29	129	25	129	25	131	26	133	25.5	125	27	132	26	130	27	128	28
46 C. (115 F.), 50 g., 5 sec.	soft	88	.....	84	.....	84	.....	88	.....	84	.....	83	.....	88	.....	86	.....	82
Tests on Recovered Asphalt:																		
Softening Point, deg. F. (A.S.T.M. D 36)[a]	111	147	111	146	110.5	145	111.2	146.8	115.5	147.6	111.2	145.4	110.7	147.6	110.8	144.5	110	148
Ductility at 25 C. (77 F.), (5 cm. per min.), cm. (A.S.T.M. D 113)[b]	150+	10.1	130+	11.5	140+	10	110+	10	100+	9	110+	11	150+	11.5	100+	10.5	126	11
Penetration (A.S.T.M. D 5):[c]																		
0 C. (32 F.), 200 g., 1 min.	33	13	37	12	37	12	38	13	41	13	39	13	37	12	37	13	45	17
25 C. (77 F.), 100 g., 5 sec.	127	28	125	26	127	24	128	27	121	26	123	27	127	26	128	26	121	27
46 C. (115 F.), 50 g., 5 sec.	soft	86	.....	85	.....	82	.....	89	.....	84	.....	81	.....	87	.....	85	.....	87

---

[a] Standard Method of Test for Softening Point of Bituminous Materials (Ring-and-Ball Method) (D 36 – 26), 1942 Book of A.S.T.M. Standards, Part II, p. 488

[b] Standard Method of Test for Ductility of Bituminous Materials (D 113 – 39), 1942 Book of A.S.T.M. Standards, Part II, p. 466.

[c] Standard Method of Test for Penetration of Bituminous Materials (D 5 – 25), 1942 Book of A.S.T.M. Standards, Part II, p. 483; Part III, p. 194.

it had been hoped to expand them and, at the same time, provide for tests of coarser gradings. However, preliminary investigations of the problems of testing coarser gradings reveal that further research is needed before satisfactory recommendations can be derived, and accordingly it is felt that the revisions already tentatively adopted, which have proved acceptable, should no longer be continued as tentative revisions of the existing standard.

TABLE II.—COOPERATIVE WORK ON RECOVERY OF ASPHALT FROM PAVEMENT SAMPLES BY MODIFIED ABSON METHOD.

	The Texas Co.	Virginia State Highway Dept.	Chicago Testing Laboratory	Michigan State Highway Dept.	Arizona State Highway Dept.	Wisconsin State Highway Dept.	A. W. Dow, Inc.	New Jersey State Highway Dept.
SAMPLE FROM THE TEXAS CO., BEACON, N. Y. (LABORATORY MIXED)								
Recovered Asphalt, per cent	10.3	10.21	11.3	....	....	10.2	10.2	10.8
Tests on Recovered Asphalt:								
Penetration at 25 C. (77 F.), 100 g., 5 sec. (A.S.T.M. D 5)[a]	59	54.4	60	54	52	51	52	57
Ductility at 25 C. (77 F.), (5 cm. per min.), cm. (A.S.T.M. D 113)[b]	103	110+	98	105	70	65	85	56
Ash, per cent (A.S.T.M. D 271)[c]	0.40	0.23	0.28	0.27	0.41	0.41	0.33	0.16
SAMPLE FROM WISCONSIN HIGHWAY DEPARTMENT (ROAD SAMPLE)								
Recovered Asphalt, per cent	5.8	6.12	5.9	....	5.81	6.1	6.05	6.07
Tests on Recovered Asphalt:								
Penetration at 25 C. (77 F.), 100 g., 5 sec. (A.S.T.M. D 5)[a]	35	35	31	34	30	28	30	37-50
Ductility at 25 C. (77 F.), (5 cm. per min.), cm. (A.S.T.M. D 113)[b]	150+	105+	140+	150+	150+	110+	100+	150+
Ash, per cent (A.S.T.M. D 271)[c]	1.97	1.11	0.15	1.46	0.87	1.98	0.82	1.0
SAMPLE FROM MICHIGAN HIGHWAY DEPARTMENT (ROAD SAMPLE)								
Recovered Asphalt, per cent	5.4	5.54	5.4	....	5.34	5.3	5.4	5.3
Tests on Recovered Asphalt:								
Penetration at 25 C. (77 F.), 100 g., 5 sec. (A.S.T.M. D 5)[a]	64	60	57	59	56	57	57	60
Ductility at 25 C. (77 F.), (5 cm. per min.), cm. (A.S.T.M. D 113)[b]	150+	105+	140+	150+	150+	110+	100+	150+
Ash, per cent (A.S.T.M. D 271)[c]	1.20	0.68	0.02	0.62	0.55	0.88	0.48	0.4

[a] Standard Method of Test for Penetration of Bituminous Materials (D 5 - 25), 1942 Book of A.S.T.M. Standards, Part II, p. 483; Part III, p. 194.

[b] Standard Method of Test for Ductility of Bituminous Materials (D 113 - 39), 1942 Book of A.S.T.M. Standards, Part II, p. 466.

[c] Standard Methods of Laboratory Sampling and Analysis of Coal and Coke (D 271 - 43), 1943 Supplement to Book of A.S.T.M. Standards, Part III, p. 1.

NOTE 1.—Chicago Testing Laboratory—centrifuged for 15 min. in 250-ml. batches in Sharples super-centrifuge.

NOTE 2.—Chicago Testing Laboratory, Michigan, and Arizona used a Rotarex for extraction instead of the specified extractor.

III. ADOPTION OF TENTATIVE STANDARDS AS STANDARD

The committee recommends that the following tentative standards be approved for reference to letter ballot of the Society for adoption as standard:

Tentative Specifications for:

Tentative Volume Correction Table for Tar and Coal-Tar Pitch (D 633 - 41 T), submitted jointly with Committee D-8 on Bituminous Waterproofing and Roofing Materials.

Crushed Stone, Crushed Slag, and Gravel for Water-Bound Macadam Base and Surface Courses of Pavements (D 694 - 42 T), and

Crushed Stone and Crushed Slag for Bituminous Macadam Base and Surface Courses of Pavements (D 693 - 42 T), revised as follows:

Section 5.—Replace Notes 1 and 2 in this section by the following:

Note.—Sizes have been selected from the Tentative Specifications for Standard Sizes of Coarse Aggregate for Highway Construction (A.S.T.M. Designation: D 448). An appropriate size should be selected for each use, depending on thickness of the base or surface course, quality of the aggregate, and on other local construction and service conditions.

For the harder aggregates, any of the sizes specified for penetration course aggregate may be appropriate, depending upon characteristics of the construction. For softer aggregates which tend to break down under the roller, the larger sizes should be used. The line of demarcation between harder and softer aggregates may be fixed conveniently by selection of limiting percentages of wear, Los Angeles machine, depending on characteristics of aggregates available in each locality.

The size of choke aggregate best suited for the work depends upon the size of surface voids in the penetration course and on fluidity of the bituminous binder. The more fluid binders require a densely graded choke aggregate (sizes 67 or 78), while the open gradations of aggregate are more suitable for the more viscous hot-application binders. The following combinations of size numbers are suggested:

Size of Penetration Course Aggregate	Size of Choke Aggregate	
	Viscous Binders	Fluid Binders
1	5	67
2	5 or 6	67 or 78
3	6 or 7	78

The size of seal-coat aggregate depends upon the type of surface desired.

Committee D-4 at a meeting on June 27, 1944, received certain recommendations from the Joint Subcommittee, of Committees D-4 and D-18, on Tests and Specifications for Stabilized Soils. As a result it has referred to letter ballot the adoption as standard of the following tentative methods:

Tentative Methods of:

Test for Moisture-Density Relations of Soil-Cement Mixtures (D 558 – 40 T) with the revisions as given in the report of Committee D-18,[4]

Wetting-and-Drying Test of Compacted Soil-Cement Mixtures (D 559 – 40 T), and

Freezing-and-Thawing Test of Compacted Soil-Cement Mixtures (D 560 – 40 T).

Contingent upon favorable letter ballot and also upon a similar recommendation from Committee D-18, Committee D-4 recommends that the Society accept these tentative standards for immediate publication as standard and accordingly asks for a nine-tenths vote of approval of this recommendation at the annual meeting.

IV. STANDARDS AND TENTATIVE STANDARDS CONTINUED WITHOUT REVISION

Owing to wartime conditions, many subcommittees are temporarily inactive and Committee D-4 has not been able to secure definite recommendations from all subcommittees responsible for the development of the following tentative standards which have been published without revision for a number of years. Committee D-4 therefore recommends that they be continued as tentative without revision.

Tentative Specifications for:

Standard Sizes of Coarse Aggregate for Highway Construction (D 448 – 42 T),

Materials for Stabilized Base Course (D 556 – 40 T),

Materials for Stabilized Surface Course (D 557 – 40 T),

Cut-Back Asphalt (Rapid Curing Type) (D 597 – 40 T),

Cut-Back Asphalt (Medium Curing Type) (D 598 – 40 T),

Crushed Stone, Crushed Slag, and Gravel for Bituminous Concrete Base and Surface Courses of Pavements (D 692 – 42 T),

Tentative Methods of Test for:

Loss on Heating of Oil and Asphaltic Compounds (D 6 – 39 T). A cooperative study of this method by members of Subcommittee B-18 on Loss on Heating (E. B. Tucker, chairman) has shown the need for revision in order to secure more reliable results on materials having high losses. This matter is under further investigation.

Tentative Methods of Sampling:

Stone, Slag, Gravel, Sand, and Stone Block for Use as Highway Materials (D 75 – 42 T),

Bituminous Materials (D 140 – 41 T), and

Tentative Revision of Standard:

Methods of Chemical Analysis of Calcium Chloride (D 345 – 34).

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 122 members; 95 members returned their ballots with the results shown in Table III.

---

[4] See p. 497.

TABLE III.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. NEW TENTATIVE STANDARD			
Test for Hot Extraction of Asphaltic Materials and Recovcovery of Bitumen by the Modified Abson Procedure	80	4	11
II. ADOPTION AS STANDARD OF TENTATIVE REVISION OF STANDARD			
Test for Ductility of Bituminous Materials (D 113 - 39; ASA A37.11 - 1943)	82	2	11
Test for Abrasion of Coarse Aggregate by Use of the Los Angeles Machine (C 131 - 39)	72	0	7
III. ADOPTION OF TENTATIVE STANDARDS AS STANDARD			
Spec. for Crushed Stone, Crushed Slag, and Gravel for Water-Bound Macadam Base and Surface Courses of Pavements (D 694 - 42 T)	70	2	23
Spec. for Crushed Stone and Crushed Slag for Bituminous Macadam Base and Surface Courses of Pavements (D 693 - 42 T) as revised	61	0	16
Volume Correction Table for Tar and Coal-Tar Pitch (D 633 - 41 T)	65	0	30
Method of Test for Moisture-Density Relations of Soil-Cement Mixtures (D 558 - 40 T), as revised	63	0	14
Method of Wetting-and-Drying Test of Compacted Soil-Cement Mixtures (D 559 - 40 T)	61	2	14
Method of Freezing-and-Thawing Test of Compacted Soil-Cement Mixtures (D 560 - 40 T)	61	3	13

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, Shreve Clark.
First Vice-Chairman, W. J. Emmons.
Second Vice-Chairman, A. T. Goldbeck.
Third Vice-Chairman, F. D. Rhodes.
Secretary, Prévost Hubbard.

This report has been submitted to letter ballot of the committee which consists of 122 members; 95 members returned their ballots, of whom 85 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the committee,

C. N. FORREST,
Chairman.

PRÉVOST HUBBARD,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-4 and Committee D-18 on Soils for Engineering Purposes presented to the Society through Committee E-10 on Standards a proposed Tentative Method of Test for Determining Cement Content of Soil-Cement Mixtures. The new tentative method was accepted by Committee E-10 on August 28, 1944, and appears in the 1944 Book of A.S.T.M. Standards, Part II, p. 1402, under the designation D 805 - 44 T.

REPORT OF COMMITTEE D-5

ON

COAL AND COKE

Committee D-5 on Coal and Coke held a meeting in Cincinnati, Ohio, on February 28, 1944; another meeting will be held at the Annual Meeting of the Society in June, 1944, in New York, N. Y. Meetings of Subcommittee I on Methods of Testing, Subcommittee XV on Plasticity and Swelling of Coal, and a section of Subcommittee XIII on Coal Sampling, designated as Special Section on Sampling Coal for Volatile Matter Determination in Connection with City Smoke Ordinances, were held in Cincinnati, Ohio, on February 28, 1944; and on October 27, 1943, a meeting of Subcommittee XIII on Coal Sampling was held in Pittsburgh, Pa.

It is with deep regret that the committee announces the sudden death on June 14, of Dr. Horace C. Porter who for many years has rendered valuable technical and administrative services as vice-chairman of the committee and as chairman of Subcommittee II on Nomenclature and Definitions.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, A. C. Fieldner.
Vice-Chairman, O. O. Malleis.
Secretary, W. A. Selvig.

A. W. Gauger has been appointed to serve as chairman of Subcommittee II on Nomenclature and Definitions.

During the year there was one resignation from the committee and one new member was added. The present membership of Committee D-5 is 53, of whom 15 are classified as producers, 17 as consumers, and 21 as general interest members.

I. Revision of Standard, Immediate Adoption

Standard Method for Designating the Size of Coal from Its Screen Analysis (**D 431 – 38**).[1]—The committee recommends for immediate adoption the following revisions in Method D 431, prepared by Subcommittee XIX on Designation of Coal Sizes (J. D. Doherty, chairman), and accordingly asks for a favorable nine-tenths vote at the Annual Meeting in order that these modifications may be referred to letter ballot of the Society:

Section 4.—Change to read as follows by the addition of the italicized words and figures and the omission of those in brackets:

4. The designation shall indicate the range of the size by giving the [lower] *upper* and [upper] *lower* limiting screens between which more than 80 per cent of the sample is retained by actual test, the limiting screens being selected as follows:

(*a*) The screen defining the [lower] *upper* limit shall be the [largest] *smallest* screen of the series given in Section 3 [through which passes] *upon which is retained* a total of less than [15] *5* per cent of the sample. The screen defining the [upper] *lower* limit shall be the [smallest] *largest* screen of the series given in Section 3 [upon which is retained] *through which passes* a total of less than [5] *15* per cent of the sample.

(*b*) The terms for defining sizes shall be written with the [lower] *upper* limiting screen first, followed by [a dash] *an "X"* and that followed by the [upper] *lower* limiting screen. The abbreviation "in." shall follow the [upper] *lower* limiting screen but may be omitted after the [lower] *upper* limiting screen. For screens of the U. S. standard sieve series (No. 4 and smaller), the abbreviation "No." shall be used each time a screen is indicated. If the total retained on the 8-in. screen is 5 per cent or greater, the size shall be designated by the lower limiting screen preceded by the word "plus" and followed by an expression in parentheses giving the percentage over 8 in. to the nearest 1 per cent.

---

[1] 1942 Book of A.S.T.M. Standards, Part III.

(*c*) The following examples illustrate the system of size designation.

Examples: plus ½ in. (10 per cent over 8 in.)
plus 4 in. (24 per cent over 8 in.)
plus No. 16 (6 per cent over 8 in.)
[2–4 in.] *4 x 2 in.*
[½–3 in.] *3 x ½ in.*
[No. 4–2 in.] *2 in. x No. 4*
[No. 30–No. 4] *No. 4 x No. 30*
[No. 50–1 in.] *1 in. x No. 50*

Note 2.—In the first sentence change "Anthracite Institute" to read "Anthracite Committee of the Production Control Plan for the Anthracite Industry" and "Institute" to read "Anthracite Committee."

Appendix.—Delete the Appendix on condensed size designation which was published for information only and was not a part of the standard method.

II. ADOPTION OF TENTATIVE STANDARD AS STANDARD

Tentative Definitions of the Terms Gross Calorific Value and Net Calorific Value of Fuels (**D 407 – 35 T**).[1]—The committee recommends that these definitions, revised as follows, be approved for reference to letter ballot of the Society for adoption as standard:

Insert the alternate term "(Gross Heat of Combustion)" immediately after the term "Gross Calorific Value," and the alternate term "(Net Heat of Combustion)" immediately after the term "Net Calorific Value" throughout the definitions.

Note.—Change the note at the end of the definitions to read as follows by the addition of the italicized words and figures and the omission of those in brackets:

NOTE.—The net calorific value (*net heat of combustion*) is calculated from the gross calorific value (*gross heat of combustion*) *at 68 F.* (*20 C.*) by making a deduction of [1020] *1030* Btu. per lb. ([567] *572* cal. per g.) of water derived from unit quantity of fuel, including both the water originally present as moisture and that formed by combustion. The deduction is not equal to the latent heat of vaporization of water [1050 Btu. per lb. at 75 F. (24 C.)] (*1055 Btu. per lb. at 68 F.* (*20 C.*)) because the calculation is made to reduce from gross value at constant volume to net value at constant pressure, for which the [correct] *appropriate* factor *under these conditions* is [1020] *1030* Btu. per lb.

III. ADOPTION OF TENTATIVE REVISION OF STANDARD AS STANDARD

Standard Methods of Laboratory Sampling and Analysis of Coal and Coke (**D 271 – 43**).[2]—The committee recommends that the tentative revision[3] of these methods submitted June, 1943, consisting of the addition of a Note 3 under Section 11 giving instructions for determination of ash in coals unusually high in calcite and pyrite, be approved for reference to letter ballot of the Society for adoption as standard.

IV. EDITORIAL CHANGES IN STANDARDS

Standard Method of Tumbler Test for Coke (**D 294 – 29**).[1]—The following editorial change in this method is recommended as it has not been clear to some that the shaft should extend through the drum; also it is desirable to specify the thickness of the shaft:

Section 2(*a*).—Change the fourth sentence from its present form: namely, "The drum shall be mounted on a horizontal shaft to provide for rotating the drum" to read as follows: "To provide for rotating the drum, it shall be mounted on a horizontal steel shaft $1\frac{1}{2}$ in. in diameter passing through the drum."

---

[2] 1943 Supplement to Book of A.S.T.M. Standards, Part III.

[3] *Proceedings*, Am. Soc. Testing Mats., Vol. 43, pp. 289 and 290 (1943).

Standard Methods of Laboratory Sampling and Analysis of Coal and Coke (**D 271 - 43**).[2]—Adoption as standard of the revised Tentative Definitions of Terms Gross Calorific Value and Net Calorific Value of Fuels (D 407 - 35 T), recommended earlier in this report, will necessitate the following editorial changes in Methods D 271:

Section 42.—Change the second paragraph of Note 3 to read as follows by the addition of the italicized words and the omission of those in brackets:

> The results obtained by the above method of calculation and determination is the [total heat of combustion] *gross calorific value (gross heat of combustion)* at constant volume, with the water in the products of combustion condensed to liquid at the temperature of the calorimeter, that is, about 20 to 35 C.
>
> [Net heat of combustion] *net calorific value (net heat of combustion)* at [20 deg.] *20 C.* (*68 F.*), shall refer to results corrected for latent heat of vaporization, as follows:
>
> $$N = B - [1040]\ \mathit{1030}\ (H \times 9)$$
>
> also:
>
> $$N' = C - [580]\ \mathit{572}\ (H \times 9)$$
>
> where:
>
> N = [net heat of combustion] *net calorific value (net heat of combustion)* in Btu. per pound,
> N′ = [net heat of combustion] *net calorific value (net heat of combustion)* in calories per gram,
> B = [total heat of combustion] *gross calorific value (gross heat of combustion) at 20 C.* (*68 F.*) in Btu.
> H = total hydrogen, and
> C = [total heat of combustion] *gross calorific value (gross heat of combustion) at 20 C.* (*68 F.*) in calories.

V. TENTATIVE STANDARDS CONTINUED AS TENTATIVE WITHOUT REVISION

It is recommended that the following tentative standards, which have stood for two years or more without revision, be continued as tentative because further developments are in progress or in prospect:

Method of Test for Grindability of Coal by the Hardgrove-Machine Method (D 409 - 37 T),
Method of Test for Grindability of Coal by the Ball-Mill Method (D 408 - 37 T),
Method of Drop Shatter Test for Coal (D 440 - 37 T), and
Method of Tumbler Test for Coal (D 441 - 37 T).

VI. STANDARDS SIX YEARS WITHOUT REVISION

The following standards have been published for six years or longer without revision and are considered by the committee to be in accord with present practice and are recommended for continuance in their present form:

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. REVISION OF STANDARD, IMMEDIATE ADOPTION			
Method for Designating the Size of Coal from Its Screen Analysis (D 431 - 38, ASA M20.3 - 1938)	38	0	2
II. ADOPTION OF TENTATIVE STANDARD AS STANDARD			
Def. of the Terms Gross Calorific Value and Net Calorific Value of Fuels (D 407 - 35 T), as revised	36	0	4
III. ADOPTION OF TENTATIVE REVISION OF STANDARD AS STANDARD			
Methods of Laboratory Sampling and Analysis of Coal and Coke (D 271 - 43, ASA K18.1 - 1944)	39	0	1
IV. EDITORIAL CHANGES IN STANDARDS			
Method of Tumbler Test for Coke (D 294 - 29, ASA K20.3 - 1936)	36	0	4
Methods of Laboratory Sampling and Analysis of Coal and Coke (D 271 - 43 ASA K18.1 - 1944)	36	0	4

Standard Specifications for:

Gas and Coking Coals (D 166 - 24),
Classification of Coals by Rank (D 388 - 38),
Classification of Coals by Grade (D 389 - 37),

Standard Methods of:

Test for Volume of Cell Space of Lump Coke (D 167 - 24),

- Drop Shatter Test for Coke (D 141 – 23),
- Sampling and Fineness Test of Powdered Coal (D 197 – 30),
- Sieve Analysis of Crushed Bituminous Coal (D 311 – 30),
- Test for Cubic Foot Weight of Crushed Bituminous Coal (D 291 – 29),
- Sampling Coke for Analysis (D 346 – 35),
- Tumbler Test for Coke (D 294 – 29),
- Sieve Analysis of Coke (D 293 – 29)
- Test for Cubic Foot Weight of Coke (D 292 – 29),
- Screen Analysis of Coal (D 410 – 38),
- Test for Size of Anthracite (D 310 – 34), and
- Standard Definitions of Terms Relating to Coal and Coke (D 121 – 30).

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 54 members; 40 members returned their ballots with the results shown in Table I.

Activities of Subcommittees

Subcommittee I on Methods of Testing (W. A. Selvig, chairman) has under consideration a revision of the permissible differences in duplicate determinations of volatile matter for anthracite, low-temperature coke, and subbituminous coal. From the data assembled it is probable that more liberal tolerances will be recommended than those now given in Section 43 of the Standard Methods of Laboratory Sampling and Analysis of Coal and Coke (D 271 – 43). A paper by W. A. Selvig on "Precision of the Volatile Matter Determination for Anthracite, Low-Temperature Coke and Subbituminous Coal,"[4] gives a statistical study of the precision of this determination from data obtained in the Coal Analysis Laboratory of the U. S. Bureau of Mines at Pittsburgh, Pa.

Subcommittee II on Nomenclature and Definitions (H. C. Porter, chairman) recommends that the Tentative Definitions of the Terms Gross Calorific Value and Net Calorific Value of Fuels (D 407 – 35 T) be revised as described earlier in this report and adopted as standard.

Subcommittee VII on Pulverizing Characteristics of Coal. (John Van Brunt, chairman) is awaiting completion of the experimental work in progress in the laboratories of the Babcock and Wilcox Co. which may lead to improvements in the tentative methods for grindability of coal (D 408–37 T and D 409 – 37 T).

Subcommittee XIII on Coal Sampling (Henry F. Hebley, chairman), through a special section has been active in conducting sampling experiments on small lots of coal in connection with plans to develop procedures for sampling coal for the determination of volatile matter in connection with city smoke ordinances.

Subcommittee XV on Plasticity and Swelling of Coal (C. C. Russell, chairman) is arranging for cooperative tests using the methods for determining plastic properties of coals and their expansion and pressure characteristics in coke ovens which were published as information[5] in the 1943 Report of Committee D-5. During the year three papers were prepared covering coal plasticity and pressures developed during carbonization of coals, as follows: "Significance of Some Criteria of Coal Plasticity" by H. H. Lowry and C. O. Junge, Jr., presented September 9, 1943, at Pittsburgh, Pa., before the Gas and Fuel Division, American Chemical Society; "Sources of Pressure Occurring During the Carbonization of Coal" by G. C. Soth and C. C. Russell, presented on October 29, 1943, at Pittsburgh, Pa., before the Annual Joint Fuels Division of the A.S.M.E. Fuels Division and the A.I.M.E. Coal Division and "A Carbonization Pressure Gage" by M. A.

---

[4] *Report of Investigations 3739*, U. S. Bureau of Mines (1943).

[5] *Proceedings*, Am. Soc. Testing Mats., Vol. 43, pp. 297 and 301 (1943).

Mayers and J. A. Thompson, A.I.M.E. *Technical Publication No. 1631* (1943).

This report has been submitted to letter ballot of the committee which consists of 54 members; 40 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

A. C. FIELDNER,
Chairman.

W. A. SELVIG,
Secretary.

REPORT OF COMMITTEE D-6

ON

PAPER AND PAPER PRODUCTS

Committee D-6 on Paper and Paper Products held one meeting during the year, on June 29, 1943, in Pittsburgh, Pa.

Cooperative relations are being continued between Committee D-6 and other A.S.T.M. committees, as well as other standardizing bodies.

At the present time, Committee D-6 consists of 63 members, of whom 51 are voting members; 25 are classified as producers, 17 as consumers, 16 as general interest, and 5 as consulting members.

I. NEW TENTATIVE STANDARDS

The committee recommends that the following new methods, prepared by Subcommittees I and IV, be accepted for publication as tentative, as appended hereto:[1]

Tentative Methods of Test for:

Adhesiveness of Gummed Tape,
Bursting Strength of Paper,
Drop Tests for Shipping Containers,
Effect of Heating on the Folding Endurance of Paper,
Flammability of Treated Paper and Paperboard,
Hydrogen Ion Concentration (pH),
Penetration by Water of Sized Paper and Paper Products (Dry Indicator Method),
Printing Ink Permeation of Paper (Castor Oil Test),
Puncture and Stiffness Testing of Paperboard, Corrugated and Solid Fiberboard,
Testing Containers in the Small Revolving Hexagonal Drum-Box Testing Machine, and
Water Vapor Permeability of Paper and Paperboard.

II. ADOPTION OF TENTATIVE STANDARDS AS STANDARD

The committee recommends that the following seven tentative standards[2] be approved without change for reference to letter ballot of the Society for adoption as standard:

Tentative Methods of:

Test for Opacity of Paper and Paper Products (D 589 - 40 T),
Test for Moisture in Paper, Paperboard, and Paperboard and Fiberboard Containers (D 644 - 42 T),
Test for Basis Weight of Paper and Paper Products (D 646 - 42 T)
Conditioning Paper and Paper Products for Testing (D 685 - 42 T),
Quantitative Determination of Coating on Mineral-Coated Paper (D 687 - 42 T),
Test for Pentosans in Paper (D 688 - 42 T), and
Test for Internal Tearing Resistance of Paper (D 689 - 42 T)

III. TENTATIVE STANDARDS CONTINUED AS TENTATIVE

The remaining tentative standards under the jurisdiction of Committee D-6, although requiring no revision, are recommended for continuation as tentative in their present form.

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 51 voting members, 43 members returned their ballots with the results as shown in Table I.

---

[1] These methods were accepted as tentative by the Society and appear in the 1944 Book of A.S.T.M. Standards, Part III.

[2] 1942 Book of A.S.T.M. Standards, Part III.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Paper Testing Methods (W. R. Willets, chairman) has held two meetings during the year. It has been active on developing new methods of test and has also continued its critical study of various methods of test of paper and paper products that have been adopted by other agencies, for example, those of the Technical Association of the Pulp and Paper Industry. The subcommittee prepared eight new methods of test which are being recommended for publication as tentative, as mentioned earlier in this report.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. NEW TENTATIVE STANDARDS			
Test for Adhesiveness of Gummed Tape	34	1	8
Test for Bursting Strength of Paper	40	0	3
Drop Test for Shipping Containers	31	0	12
Test for Effect of Heating on the Folding Endurance of Paper	32	0	11
Test for Flammability of Treated Paper and Paperboard	32	0	11
Test for Hydrogen Ion Concentration (pH)	31	2	10
Test for Time of Penetration by Water of Sized Paper and Paper Products (Dry Indicator Method)	34	0	9
Test for Printing Ink Permeation of Paper (Castor Oil Test)	33	0	10
Puncture and Stiffness Testing of Paperboard, Corrugated and and Solid Fiberboard	34	0	9
Testing Containers in the Small Revolving Hexagonal Drum-Box Testing Machine	30	1	12
Test for Water Vapor Permeability of Paper and Paperboard	35	0	8
II. ADOPTION OF TENTATIVE STANDARDS AS STANDARD			
Test for Opacity of Paper and Products (D 589 – 40 T)	32	0	11
Test for Moisture in Paper, Paperboard, and Paperboard and Fiberboard Containers (D 644 – 42 T)	36	0	7
Test for Basis Weight of Paper and Paper Products (D 646 – 42 T)	37	0	6
Conditioning Paper and Paper Products for Testing (D 685 – 42 T)	34	2	7
Quantitative Determination of Coating on Mineral-Coated Paper (D 687 – 42 T)	30	0	13
Test for Pentosans in Paper (D 688 – 42 T)	30	0	13
Test for Internal Tearing Resistance of Paper (D 689 – 42 T)	33	1	9

Six of the seven tentative methods being recommended for adoption as standard are also under the jurisdiction of this subcommittee.

Methods on the following subjects are being given consideration by Subcommittee I:

Stretch of Paper and Paperboard,
Test for Sulfates and Chlorides in Paper,
Tensile Breaking Strength of Paper,
Wet Tensile Strength of Paper,
Creasing of Paper for Water Vapor Permeability Test,
Edge Tear of Paper,
Erasing Properties of Paper,
Fiber Composition of Paper,
Lint on Paper,
Sizing Tests of Paper,
Smoothness of Paper, and
Stiffness of Paper.

In addition to the above, work has been completed on the following proposed methods which have been referred to the Joint A.S.T.M.-TAPPI Committee for action:

Test for Absorption of Bibulous Papers of Water and Writing Ink, and
Test for Ply Adhesion of Paper and Vulcanized Fiber.

After preparing a complete method covering the wax pick test for surface strength of paper, the subcommittee decided not to recommend its publication as tentative, due to the fact that there are no standards available for the waxes which it is necessary to use in the test.

The work on methods for curl of paper and gloss of paper has been discontinued for the present, because it was considered that a fairly large amount of research and laboratory work would be necessary which, during these times, could not be carried out. These methods will be given consideration at some later date.

Subcommittee II on Significance of Test Methods (C. C. Heritage, chairman) held one meeting during the year, at which plans were completed for the publication this year of the monograph on "Paper and Paperboard, Characteristics, Nomenclature, and Significance of Tests."[3] It will include a discussion of paper manufacture and the nature of paper from the chemical standpoint and as a complex structure; also the action of water on paper and its significance, and a detailed discussion of the properties of various classes of paper and paperboard. The individual tests applied to paper and paperboard and their significance are also discussed at considerable length in this publication. Also included is an Index and a very complete cross-reference list of A.S.T.M. and TAPPI methods of tests.

Subcommittee IV on Fiberboard and Fiberboard Containers (R. L. Beach, chairman) has held two meetings during the year. At the first meeting, a rather exhaustive testing program was established to develop a number of methods which appear to be badly needed in the industry. The subcommittee prepared three new methods of test which are being recommended for publication as tentative, as mentioned earlier in this report.

One of the seven tentative methods being recommended for adoption as standard is also under the jurisdiction of this subcommittee.

Methods on the following subjects are being given consideration by Subcommittee IV:

Tape Test on Taped Joints,
Beam Test,
Adhesion Test- Combined Corrugated Board,
Immersion and Delamination Test,
Surface Moisture Test,
Score Line Tests, and
Impact Strength of Paperboard Boxes.

The Advisory Committee has recommended that Subcommittee III, which originally covered paper bags, be reinstated with a new personnel. The reinstatement of Subcommittee III is progressing in an orderly fashion, but has not yet reached the point where a report can be submitted.

A Nominating Committee consisting of the chairmen of the subcommittees of Committee D-6, namely, W. R. Willets (chairman), C. C. Heritage, and R. L. Beach, submitted the following nominations for officers of the committee for the next two years which will be voted on at the meeting of Committee D-6 held in June during the Annual Meeting of the Society:

Chairman, L. S. Reid
Vice-Chairman, M. A. Krimmel
Secretary, G. H. Harnden

At the same time, the Nominating Committee recommended that the members-at-large of the Advisory Committee for the next two years be as follows:

E. G. Ham,
K. P. Geohegan,
M. S. Kantrowitz, and
R. G. MacDonald.

The above officers and members of the advisory committee were elected for the ensuing term of two years.

During the year, the first issue of the compilation of "A.S.T.M. Standards on Paper and Paper Products," which was prepared by Committee D-6, was published. This compilation contains 31 methods of test, 27 of which were prepared by the subcommittees of Committee D-6, and 6 specifications on paper products which were prepared by standing committees other than Committee D-6.

---

[3] Issued as separate publication in October, 1944.

This report has been submitted to letter ballot of the committee, which consists of 51 voting members; 43 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

L. S. REID,
Chairman.

G. H. HARNDEN,
Secretary.

REPORT OF COMMITTEE D-7
ON
TIMBER

Committee D-7 on Timber held one meeting during the year in Chicago, Ill., on March 14, 1944.

The most important business transacted during the year was the organization of a new Subcommittee XII on Fire-Retardant Wood of which W. H. Fulweiler is chairman. The new subcommittee, consisting of eleven members, is intrusted with the study, development, and interpretation of specifications for testing fire-resistive treated wood. It is possible that the subcommittee will have other phases of the fire-resistive treatment of wood assigned to it for study from time to time. This subcommittee will cooperate with Subcommittee II on Fire Tests of Lumber, of Committee C-5, of which W. J. Krefeld is chairman.

During the past year, Subcommittee IX on Methods of Testing (L. J. Markwardt, chairman) has had under consideration the development of methods of testing veneer, plywood, and wood and wood-base laminates. The expanding use of these materials and the need for evaluating their mechanical properties has stimulated interest in methods of testing. In the preparation of the methods, consideration was given to procedures already in satisfactory use for these materials, and to the correlation of the methods with related procedures already in use, or under consideration, for other materials. In addition to consideration by Subcommittee IX, the tentative draft was submitted to a number of interested organizations and individuals for comment and criticism, and all suggestions received were carefully considered. In accordance with action taken at the March meeting of Committee D-7, the procedures recommended by Subcommittee IX are published as information in the Appendix[1] to this report, pending formal action regarding their submittal for publication as tentative.[2]

Subcommittee VI on Timber Preservatives (C. S. Reeve, chairman) has for some time been considering the advisability of making certain revisions in the Standard Specifications for Creosote-Coal Tar Solution (D 391 – 36). While there is fair agreement among the membership of Subcommittee VI, it was believed that it would be undesirable to revise these specifications during the coming year. No revisions have been considered or recommended in the Standard Specifications for Zinc Chloride (D 432 – 39) or in the Standard Methods of Chemical Analysis of Zinc Chloride (D 199 – 27). The subcommittee plans to recommend a considerable number of revisions in these two standards to bring them up to date, but it is impossible to present these in any definite form at this time. This is one of the items on the agenda of the committee looking toward submittal of the proposed revisions next year.

---

[1] These methods were accepted as tentative by the Society and appear in the 1944 Book of A.S.T.M. Standards, Part II.

[2] See Editorial Note, p. 416.

The following standards under the jurisdiction of Committee D-7 have now been published for six years or longer without revision. These standards have been carefully reviewed and they should all be continued without any changes. Most of them are now the accepted standards of other engineering bodies and Governmental bureaus and will probably not require any changes for some time to come:

D 9 - 30
D 38 - 33
D 25 - 37
D 52 - 20
D 245 - 37
D 347 - 33
D 390 - 36
D 143 - 27
D 370 - 33
D 168 - 30
D 198 - 27
D 199 - 27
D 367 - 33
D 368 - 33
D 369 - 33

The election of officers for the ensuing term of two years resulted in the selection of the following

Chairman, Hermann von Schrenk.
Secretary, L. J. Markwardt.

This report has been submitted to letter ballot of the committee which consists of 31 members; 31 members returned their ballots, of whom 30 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the committee,

HERMANN VON SCHRENK,
Chairman.

L. J. MARKWARDT,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-7 presented to the Society through Committee E-10 on Standards proposed Tentative Methods of Testing Veneer, Plywood, Wood, and Wood-Base Laminated Materials. The new tentative methods were accepted by Committee E-10 on August 28, 1944, and appear in the 1944 Book of A.S.T.M. Standards, Part II, p. 1453, under the designation D 805 - 44 T.

REPORT OF COMMITTEE D-8

ON

BITUMINOUS WATERPROOFING AND ROOFING MATERIALS

Committee D-8 on Bituminous Waterproofing and Roofing Materials held one meeting during the year, in Pittsburgh, Pa., on June 28, 1943.

Subsequent to the 1943 Annual Meeting, Committee D-8 presented to the Society through Committee E-10 on Standards, the following recommendations under the emergency procedure:

Emergency Alternate Provisions:

Standard Methods of Testing Bituminous Mastics, Grouts, and Like Mixtures (EA – D 147),

Tentative Methods of Testing Asphalt Roll Roofing, Cap Sheets, and Shingles (EA – D 228).

Additional Emergency Alternate Provisions in:

Tentative Specifications for Asphalt Roofing Surfaced with Powdered Talc or Mica (EA – D 224a), and

Tentative Specifications for Asphalt Roofing Surfaced with Coarse Mineral Granules (EA – D 249a).

These recommendations were accepted by Committee E-10 on August 30, 1943, and the emergency provisions were published in ASTM BULLETIN No. 125, December, 1943, and have also been issued in the form of stickers for attachment to the standards to which they apply.

On April 14, 1944, proposed Emergency Alternate Specifications for Asphalt Shingles Surfaced with Coarse Mineral Granules, submitted by Committee D-8, were accepted by Committee E-10 and assigned the designation EA – D 225.

At a meeting on June 27, 1944, Committee D-8 voted to submit to letter ballot the following recommendations involving four Emergency Alternate Provisions which will be submitted to the Society through Committee E-10 on Standards, subsequent to the annual meeting:[1]

Emergency Alternate Provision EA-D 228.—Discontinue as an emergency alternate provision and with certain revisions incorporate it as a revision in Tentative Methods of Testing Asphalt Roll Roofing, Cap Sheets, and Shingles (D 228 – 42 T).

Emergency Alternate Provision EA-D 224a.—Eliminate all but the provision for Section 12(*a*) and incorporate the remainder with certain revisions as a revision of Tentative Specifications for Asphalt Roofing Surfaced with Powdered Talc or Mica (D 224 – 41 T).

Emergency Alternate Provision EA-D 249a.—Continue as an emergency alternate, with certain revisions which will also be recommended as a revision of the Tentative Specifications for Asphalt Roofing Surfaced with Coarse Mineral Granules (D 249 – 42 T).

Emergency Alternate Specifications EA-D 225.—With certain editorial corrections, discontinue as an emergency alternate and incorporate it as a revision of the Tentative Specifications for Asphalt Shingles Surfaced with Coarse Mineral Granules (D 225 – 41 T).

I. REVISION OF TENTATIVE STANDARDS

Tentative Specifications for Asphalt-Saturated Asbestos Felts for Use in Waterproofing and in Contructing Built-Up Roofs (**D 250 – 42 T**).[2]—In order to indicate the relation of these specifications to Specifications D 312, the committee recommends that a new Section 3 be added to read as follows and that the subsequent sections be renumbered accordingly:

---

[1] See Editorial Note, p. 421.

[2] 1942 Book of A.S.T.M. Standards, Part II.

> 3. *Mopping Materials.*—For the construction of built-up roofs, asphalt mopping materials conforming to the Standard Specifications for Asphalt for Use in Constructing Built-Up Roof Coverings (A.S.T.M. Designation: D 312) shall be used.

Tentative Specifications for Asphalt-Saturated and Asphalt-Coated Asbestos Felts for Use in Constructing Built-Up Roofs (**D 655 – 42 T**).[2]—Committee D-8 recommends that the title of these specifications be changed by the omission of the word "Asphalt" in "Asphalt-Coated"; also that a new Section 3 be added to read the same as that recommended above in Specifications D 250, renumbering the subsequent sections accordingly.

Tentative Methods of Testing Felted and Woven Fabrics Saturated with Bituminous Substances for Use in Waterproofing and Roofing (**D 146 – 38 T**).[2]—The following revisions in these methods are recommended but since the committee is endeavoring to develop an improved method of determining the weight of saturation in coal-tar saturated felts and fabrics, it recommends that the methods be continued as tentative as revised:

Section 1.—Change to read as follows, by the addition of the italicized words and the omission of the word in brackets:

> 1. These methods cover the examination of felted or woven fabrics saturated (but not coated) with asphalt or coal-tar [products] *materials,* for use in the "membrane" system of waterproofing *or for the construction of built-up roof coverings.*

Section 16.—As none of the present specifications for felts require a distillation test, it is recommended that the distillation of coal-tar saturated felt described in this section be deleted and that the subsequent sections be renumbered accordingly.

II. REVISION OF STANDARDS, IMMEDIATE ADOPTION

As the proposed revisions of the following standards are editorial in nature and are intended to bring them into conformity with later approved forms, it is recommended that they be incorporated immediately in these standards. The committee accordingly requests the necessary nine-tenths affirmative vote at the Annual Meeting in order that these recommendations may be referred to letter ballot of the Society:

Standard Specifications for Asphalt for Use in Constructing Built-Up Roof Coverings (**D 312 – 41**):[2]

Section 1.—Delete the reference to the Standard Specifications for Asphalt-Saturated Roofing Felt for Use in Waterproofing and in Constructing Built-Up Roofs (D 226 – 42) and the Tentative Specifications for Asphalt-Saturated Asbestos Felts for Use in Waterproofing and in Constructing Built-Up Roofs (D 250 – 42 T).

New Sections.—Add new Sections 2 and 3 to read as follows, renumbering the subsequent sections accordingly:

> 2. *Primer.*—The material used as a primer when this asphalt is used over concrete and gypsum roof slabs shall be asphalt primer conforming to the Standard Specifications for Primer for Use with Asphalt in Dampproofing and Waterproofing (A.S.T.M. Designation: D 41).
>
> 3. *Membrane Materials.*—The felts for use in constructing built-up roof coverings with this asphalt shall be of the type covered by any of the following specifications:
>
> (*1*) Standard Specifications for Asphalt-Saturated Roofing Felt for Use in Waterproofing and in Constructing Built-Up Roofs (A.S.T.M. Designation: D 226),
>
> (*2*) Tentative Specifications for Asphalt-Saturated Asbestos Felts for Use in Waterproofing and in Constructing Built-Up Roofs (A.S.T.M. Designation: D 250), and

(3) Tentative Specifications for Asphalt-Saturated and Coated Asbestos Felts for Use in Constructing Built-Up Roofs (A.S.T.M. Designation: D 655).

Section 2.—Renumber as Section 4 and change Paragraph (*b*) to read as follows by the addition of the italicized words and the omission of those in brackets:

(*b*) Somewhat less susceptible asphalts for [unsurfaced] roofing *laid* on inclines up to 3 in. per ft. [and] *which are not surfaced with slag or gravel.*

Standard Specifications for Asphalt-Saturated Roofing Felt for Use in Waterproofing and in Constructing Built-Up Roofs (D 226 – 42):[2]

New Section.—Add a new Section 3 to read as follows, renumbering the subsequent sections accordingly:

3. *Mopping Materials.*—(*a*) For the construction of built-up roofs, mopping asphalts conforming to the Standard Specifications for Asphalt for Use in Constructing Built-Up Roof Coverings (A.S.T.M. Designation: D 312) shall be used.

(*b*) For the construction of a membrane system of waterproofing, types A, B, or C mopping asphalt conforming to the Tentative Specifications for Asphalt for Dampproofing and Waterproofing (A.S.T.M. Designation: D 449) shall be used depending upon service conditions as described in Section 4 of Specifications D 449.

Standard Specifications for Coal-Tar Saturated Roofing Felt for Use in Waterproofing and in Constructing Built-Up Roofs (D 227 – 42):[2]

New Section.—Add a new Section 2 to read as follows, renumbering the subsequent sections accordingly:

2. *Mopping Materials.*—(*a*) For the construction of built-up roofs on inclines not exceeding 3 in. per ft. where nailing is employed and not exceeding 1 in. per ft. where nailing is omitted, type A coal-tar pitch conforming to the Standard Specifications for Coal-Tar Pitch for Roofing, Dampproofing, and Waterproofing (A.S.T.M. Designation: D 450) shall be used.

(*b*) For the construction of steep built-up roofs with inclines of 1 to 6 in. per horizontal foot where nailing is employed, the Tentative Specifications for Coal-Tar Pitch for Steep Built-Up Roofs (A.S.T.M. Designation: D 654) may be used.

(*c*) For the construction of a membrane system of waterproofing, types A or B coal-tar pitch conforming to the Standard Specifications for Coal-Tar Pitch for Roofing, Dampproofing, and Waterproofing (A.S.T.M. Designation: D 450) shall be used depending upon the conditions of service as described in Section 4 of Specifications D 450.

Standard Specifications for Woven Cotton Fabrics Saturated with Bituminous Substances for Use in Waterproofing (D 173 – 42):[2]

New Section.—Add a new Section 2 to read as follows, renumbering the subsequent sections accordingly:

2. *Mopping Materials.*—(*a*) For the construction of a membrane system of waterproofing with cotton fabric saturated with asphalt, types A, B, or C asphalt conforming to the Tentative Specifications for Asphalt for Dampproofing and Waterproofing (A.S.T.M. Designation: D 449) shall be used depending upon the conditions of service as described in Section 4 of Specifications D 449.

(*b*) For the construction of a membrane system of waterproofing with woven cotton fabric saturated with coal-tar, coal-tar pitch conforming to the Standard Specifications for Coal-Tar Pitch for Roofing, Dampproofing, and Waterproofing (A.S.T.M. Designation: D 450) shall be used.

Section 7.—Change to read as follows by the addition of the italicized words and the omission of the word in brackets:

7. *If* the selvage *is used it* shall measure not [over] *more than* ½ in.

Section 10.—Change the first sentence to read as follows by the addition of the italicized words and the omission of the words and numbers in brackets:

The rolls of treated cotton fabric shall be wound on mandrels *or rigid hollow fiber cylinders* not less than 2 in. in diameter or 2 in. square [and] extending not [less than 2 nor] more than 4 in. beyond the ends of the rolls.

III. ADOPTION OF TENTATIVE STANDARDS AS STANDARD

The committee recommends that the following tentative standard, under the joint jurisdiction of Committee D-4 on Road and Paving Materials and Committee D-8, be approved for reference to letter ballot of the Society for adoption as standard:

Tentative Volume Correction Table for Tar and Coal-Tar Pitch (D 633 – 41 T).

The committee also recommends for adoption as standard two tentative specifications, as set forth below, and accordingly asks for a nine-tenths affirmative vote at the annual meeting in order that these modifications may be referred to letter ballot of the Society:

Specifications for Wide Selvage Asphalt Roofing Surfaced with Coarse Mineral Granules (D 371 – 41 T) with the following editorial corrections: Delete from the tenth item in Table I the words "per 108 sq. ft."

Specifications for Asphalt Siding Surfaced with Coarse Mineral Granules (D 699 – 42 T) with the following editorial corrections: Delete from the ninth item in Table I the words "per 100 sq. ft."

IV. STANDARDS AND TENTATIVE STANDARDS CONTINUED WITHOUT REVISION

Committee D-8 recommends that the following standards and tentative standards be continued without change:

Standard Specifications for Coal-Tar Pitch for Roofing, Dampproofing and Waterproofing (D 450 – 41).

Standard Method of Test for Coarse Particles in Mixtures of Asphalt and Mineral Matter (D 313 – 41).

Tentative Methods of Sampling Bituminous Materials (D 140 – 41 T).

Tentative Specifications for Coal-Tar Pitch for Steep Built-Up Roofs (D 654 – 42 T). Subcommittee IV is attempting to develop a slide test requirement for inclusion in these specifications.

Tentative Recommended Practice for Accelerated Weathering Test of Bituminous Materials (D 529 – 39 T). Subcommittee VIII is considering certain revisions of this tentative standard.

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 60 voting members; with the results shown in Table I.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. REVISION OF TENTATIVE STANDARDS			
Spec. for Asphalt-Saturated Asbestos Felts for Use in Waterproofing and in Constructing Built-Up Roofs (D 250 – 42 T)	34	0	8
Spec. for Asphalt-Saturated and Asphalt-Coated Asbestos Felts for Use in Constructing Built-Up Roofs (D 655 – 42 T)	33	0	9
Testing Felted and Woven Fabrics Saturated with Bituminous Substances for Use in Waterproofing and Roofing (D 146 – 38 T)	36	0	6
II. REVISION OF STANDARDS, IMMEDIATE ADOPTION			
Spec. for Asphalt for Use in Constructing Built-Up Roof Coverings (D 312 – 41)	34	0	8
Spec. for Asphalt-Saturated Roofing Felt for Use in Waterproofing and in Constructing Built-Up Roofs (D 226 – 42)	33	0	9
Spec. for Coal-Tar Saturated Roofing Felt for Use in Waterproofing and in Constructing Built-Up Roofs (D 227 – 42)	33	0	9
Spec. for Woven Cotton Fabrics Saturated with Bituminous Substances for Use in Waterproofing (D 173 – 42)	33	0	9
III. ADOPTION OF TENTATIVE STANDARDS AS STANDARD			
Volume Correction Table for Tar and Coal-Tar Pitch (D 633 – 41 T)	34	0	8
Spec. for Wide Selvage Asphalt Roofing Surfaced with Coarse Mineral Granules (D 371 – 41 T)	34	1	2
Spec. for Asphalt Siding Surfaced with Coarse Mineral Granules (D 699 – 42 T)	34	1	2
IV. REAPPROVAL OF EXISTING STANDARDS			
Spec. for Coal-Tar Pitch for Roofing, Damp-proofing and Waterproofing (D 450 – 41)	33	0	9
Test for Coarse Particles in Mixtures of Asphalt and Mineral Matter (D 313 – 41)	35	0	7

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, J. S. Miller.
Vice-Chairman, E. H. Berger.
Secretary, Prévost Hubbard.

This report has been submitted to letter ballot of the committee which consists of 60 voting members; 42 members returned their ballots of whom 41 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the committee,

J. M. WEISS,
Chairman.

PRÉVOST HUBBARD,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting Committee D-8 presented to the Society through Committee E-10 on Standards the following recommendations:

Revision of Tentative Specifications for:

Asphalt Roofing Surface with Powdered Talc or Mica (D 224 – 41 T) and revision of Emergency Provision EA – D 224a,
Asphalt-Shingles Surfaced with Coarse Mineral Granules (D 225 – 41 T) and withdrawal of EA – D 225,
Asphalt Roofing Surfaced with Coarse Mineral Granules (D 249 – 42 T) and revision of EA – D 249a, and

Revision of Tentative Methods of:

Testing Asphalt Roll Roofing, Cap Sheets, and Shingles (D 228 – 42 T) and withdrawal of EA – D 228a.

These recommendations were accepted by Committee E-10 on August 28, 1944, and the revised tentatives and emergency provisions appear in the 1944 Book of A.S.T.M. Standards, Part II, under the designations D 224 – 44 T, EA – D 224b, D 225 – 44 T, D 249 – 44 T, EA – D 249b, and D 228 – 44 T, respectively.

REPORT OF COMMITTEE D-9
ON
ELECTRICAL INSULATING MATERIALS

Committee D-9 on Electrical Insulating Materials held two meetings during the year and will hold a third during the Annual Meeting in June. These meetings were held in New York, N. Y., on October 26 and 27, 1943, and in Philadelphia, Pa., on February 21 and 22, 1944. At the time of the Philadelphia meeting the members of Committee D-9 cooperated with Committee D-20 on Plastics and the Philadelphia District Committee in sponsoring a very successful Symposium on Plastics.

At these meetings recommendations were made which resulted in new standards, additions to existing standards and changes in some of the standards for which Committee D-9 is responsible. Projects which are still under way are mentioned later in this report.

RECOMMENDATIONS ACCEPTED BY COMMITTEE E-10 ON STANDARDS

Subsequent to the 1943 Annual Meeting, Committee D-9 presented to the Society through Committee E-10 on Standards, the following recommendations:

New Tentative Specifications for:

Natural Block Mica and Mica Films Suitable for Use in Fixed Mica-Dielectric Capacitors (D 748 - 43 T),

New Tentative Methods of:

Measuring Dimensions of Rigid Rods Used in Electrical Insulation (D 741 - 43 T), and

Revision of Tentative Revision of:

Standard Methods of Testing Sheet and Plate Materials Used in Electrical Insulation (D 229 - 43).

The new tentative specifications were accepted[1] by Committee E-10 on November 20, 1943, and the latter two recommendations were accepted[1] on August 30, 1943. The new tentative standards and revised tentative revision appear in the 1943 Supplement to Book of A.S.T.M. Standards, Part III.

Committee D-9 and Committee D-20 on Plastics jointly submitted the following recommendations to Committee E-10 during the year:

New Tentative Specifications for:

Enclosures for Small Testing Machines for Tests at Subnormal and Supernormal Temperatures of Electrical Insulating Materials and Plastics (D 760 - 44 T),

Servicing Units for Tests at Subnormal and Supernormal Temperatures of Electrical Insulating Materials and Plastics (D 761 - 44 T), and

Revision of Tentative Methods of:

Test for Impact Resistance of Plastics and Electrical Insulating Materials (D 256 - 41 T).

The new tentative specifications were accepted[1] by the Standards Committee

---

[1] In submitting these recommendations to Committee E-10 on Standards, Committee D-9 reported the following results of the letter ballot vote from a committee membership of 97: *D 748*, 76 ballots returned, affirmative 30, negative 0, ballots marked "not voting" 46; *D 741*, 60 ballots returned, affirmative 28, negative 0, ballots marked "not voting" 32; *D 229*, 60 ballots returned, affirmative 32, negative 0, ballots marked "not voting" 28; *D 760*, 60 ballots returned, affirmative 24, negative 0, ballots marked "not voting" 36; *D 761*, 60 ballots returned, affirmative 23, negative 0, ballots marked "not voting" 37; *D 256*, 65 ballots returned, affirmative 32, negative 1, ballots marked "not voting" 32. The following results of the letter ballot vote were reported by Committee D-9 from a membership of 101: *D 468*, 67 ballots returned, affirmative 17 negative 0, ballots marked "not voting" 50.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

	Affirmative	Negative	Ballots Marked "Not Voting"
I. NEW TENTATIVE STANDARDS			
Spec. for Orange Shellac and Other Indian Lacs for Electrical Insulation	16	0	51
Test for Indentation Hardness of Plastics	27	0	40
Flexural Test of Plastics	32	1	27
II. REVISION OF TENTATIVE STANDARDS			
Test for Power Factor and Dielectric Constant of Electrical Insulating Materials (D 150 – 42 T)	37	0	30
Sampling and Testing Untreated Paper Used in Electrical Insulation (D 202 - 41 T)	27	0	40
Spec. for Phenolic Laminated Sheet for Radio Applications (D 467 – 40 T)	26	0	40
Conditioning Plastics and Electrical Insulating Materials for Testing (D 618 – 41 T)	40	1	25
Test for Heat Distortion Under Heat of Molded Electrical Insulating Materials (D 648 – 41 T)	31	0	29
III. TENTATIVE REVISIONS OF STANDARDS			
Testing Electrical Insulating Oils (D 117 – 43; ASA C59.2-1944)	29	0	[illegible]
Testing Sheet and Plate Materials Used in Electrical Insulation (D 229 – 43; C59.13-1944)	38	0	28
Testing Laminated Tubes Used in Electrical Insulation (D 348 – 42; C59.14-1943)	33	0	33
Testing Laminated Round Rods Used in Electrical Insulation (D 349 - 42; C59.15-1943)	33	0	33
Test for Grading and Classification of Natural Mica (D 351 – 38)	20	0	46
IV. ADOPTION OF TENTATIVE STANDARDS AS STANDARD			
Test for Saponification Number of Petroleum Products by Color-Indicator Titration (D 94 – 43 T)	26	0	45
Test for Dielectric Strength of Electrical Insulating Materials at Commercial Power Frequencies (D 149 – 40 T)	44	0	16
Testing Solid Filling and Treating Compounds Used for Electrical Insulation (D 176 – 42 T)	19	0	48
Testing Glass Spool Insulators (D 550 – 41 T)	20	0	46
Test for Punching Quality of Phenolic Laminated Sheets (D 617 – 41 T)	23	0	44
Test for Product Uniformity of Phenolic Laminated Sheets (D 634 – 41 T)	23	0	44
Testing Steatite Used as Electrical Insulation (D 667 – 42 T)	18	0	48
Measuring Dimensions of Rigid Tubes Used in Electrical Insulation (D 668 – 42 T)	25	0	42

TABLE I.—*Concluded*

	Affirmative	Negative	Ballots Marked "Not Voting"
V. ADOPTION AS STANDARD OF TENTATIVE REVISIONS OF STANDARD			
Testing Electrical Porcelain (D 116 – 42)	23	0	43
Testing Shellac Used for Electrical Insulation (D 411 – 42; C59.18-1944)	15	0	51
VI. WITHDRAWAL OF STANDARD			
Test for Comparing Thermal Conductivities of Solid Electrical Insulating Materials (D 325 - 31 T)	38	0	28

on February 8, 1944; the revised tentative methods were accepted[1] on September 24, 1943, and appear in the 1943 Supplement to Book of A.S.T.M. Standards, Part III, bearing the designation D 256 – 43 T.

Committee D-9 recently submitted to Committee E-10 a proposed tentative revision of the Standard Methods of Testing Pin-Type, Lime Glass Insulators (D 468 – 42) which was accepted[1] on May 3, 1944, and appears in the 1944 Book of A.S.T.M. Standards, Part III.

RECOMMENDATIONS AFFECTING STANDARDS

As the result of the year's work, the committee is submitting two new tentative standards, revisions of four tentative standards, tentative revisions of five standards, the adoption as standard of nine tentative standards, the adoption as standard of two tentative revisions of standards, and recommends the withdrawal of one tentative standard. The standards affected are listed in Table I. The recommendations being presented are included in Appendix I.

These recommendations have been submitted to letter ballot of the committee which consists of 101 voting members, with the results shown in Table I.

ACTIVITIES OF SUBCOMMITTEES

Some of the projects now in progress are briefly mentioned in the following summary of committee activities:

Subcommittee I on Insulating Varnishes, Paints, and Lacquers (C. F. Hanson, chairman).—This subcommittee has prepared Specifications for Orange Shellac and Other Indian Lacs Used for Electrical Insulation which are being submitted to the Society for publication as tentative. The tentative revisions of the Standard Methods of Testing Shellac Used for Electrical Insulation (D 411 - 42) are being recommended for adoption as standard.

The Section on Oil Resistance has under consideration a revision of the oil-proof test in the Standard Methods of Testing Varnishes Used for Electrical Insulation (D 115 - 41). It has been found in the trade that the procedure is not defined with sufficient clarity.

The Section on Deep-Drying Varnishes is actively engaged in developing a test method for determining the deep-drying properties of varnishes used for impregnating purposes. This program of work is a continuation of work which has been in progress for about 14 years. At the present time varnishes used for impregnating purposes are selected by brand, after having been approved by actual use in trial manufacturing. To set up a test method which will select an appropriate varnish for this use is most difficult because the conditions prevailing in actual use are difficult to simulate in a test method. However, during the past year's work a great deal of information has been accumulated and with this experience as a background, the section expects that a satisfactory test method or methods may soon be developed.

The work of the Section on Phenolic-Resin Varnish has been expanded to include other types of thermosetting varnishes. Accordingly, this section will be known hereafter as the Section on Thermosetting Resin Varnishes. This section has recently been reorganized with an expanded personnel, and it now has two projects on its agenda. One of these has to do with the test method for non-volatile matter by weight in the Standard Methods D 115 - 41. It has been found that the present method is not sufficiently concise for certain types of varnishes. The other project concerns the development of a test method for time of set of thermosetting varnishes.

Subcommittee II on Molded Insulating Materials (W. A. Evans, chairman).—This subcommittee has been actively cooperating with various subcommittees of Committee D-20 on Plastics and members of the Federal Government in coordinating test methods used for testing plastics. When this correlation is completed it is hoped that the test methods used by the various Government agencies will coincide with the standard A.S.T.M. test methods so far as this is practical.

Revision of the Tentative Methods of Testing Molded Materials Used for Electrical Insulation (D 48 - 43 T) is being considered from the point of view of the above mentioned correlation and to keep in step with the best procedures used in testing these materials.

A new section has been formed to write test methods and specifications for extruded plastic tubing used for electrical insulation. Committee D-20 has been asked to assist in preparing test methods for mechanical and thermal properties.

Subcommittee III on Plates, Tubes, and Rods (G. H. Mains, chairman).—The subcommittee has cooperated actively with Subcommittee II of Committee D-9, Subcommittee I of Committee D-20, and with a subcommittee of the Federal Specifications Board and this has resulted in the recommendation by Committee D-9 of tentative revisions of the methods for tension tests of sheets, tubes and rods, covered by Methods D 229, D 348, and D 349, respectively. These changes provide for improved specimens and uniformity of test methods between Committee D-9, Committee D-20, and Federal Specifications for Organic Plastics (General Specifications and Methods of Test) (LP-406).

A method of Rockwell hardness testing sponsored jointly by Committee D-20 and Committee D-9 has been prepared and involves only minor changes from the present D-9 method; this has been approved by the subcommittee.

The paper by Ladislav Boor "Indentation Hardness of Plastics,"[2] being presented at this annual meeting covers studies carried on in connection with the work of this committee.

The proposed flexural strength method, developed jointly with Subcommittee II of Committee D-9 and Subcommittee I of Committee D-20, has undergone considerable revision and is now being balloted upon by the subcommittee.

It is recommended that the Tentative Specifications for Phenolic Laminated Sheet for Radio Applications (D 467 - 40 T) be revised to eliminate grade No. 6 which has become obsolete. A revision of the method for testing dielectric strength of sheet material parallel to the laminations has been approved by the subcommittee. Active work is being conducted on a study of the effect of specimen size and conditioning on insulation resistance, also on the effect of temperature on power factor and dielectric constant of sheet materials.

A paper by E. O. Hausmann on "Heat Resistance of Laminated Plastics,"[3] covering several years work of the Section on Thermal Properties was presented at the recent Symposium on Plastics. This section is also actively studying new methods of test for measuring flammability.

Members of the subcommittee have cooperated actively with the specifications subcommittee of Committee D-20, with the American Standards Association, and with various Government agencies in preparing specifications for plastics and electrical insulating materials for the armed forces.

This subcommittee prepared the Tentative Methods of Measuring Dimensions of Rigid Rods Used in Electrical Insulation (D 741 - 43 T).

Subcommittee IV on Liquid Insulation (E. A. Snyder, chairman).—The activities of this subcommittee have been as follows:

(*1*) *Sludge Test.*—The Tentative Methods of Test for Sludge Formation in Mineral Transformer Oil (D 670 - 42 T) have been under trial for several years. One of the most important projects undertaken by Subcommittee IV is to determine whether oils which give good results by these tests will show good results under actual service conditions and, *vice versa*, whether oils showing poor test results by these methods will give correspondingly poor service. The establishment of such correlating tests has been a very difficult matter. Progress has been made to the extent that five different utility companies have agreed to set aside the required number and type of transformers which will be put under very carefully supervised operating conditions for a period of years sufficient to develop correlating data. One public utility company has been cooperative enough to produce ideal conditions in that it has agreed to isolate banks of transformers so that tests can be made under actual service conditions in practically identical transformers of three different designs with oils showing (*a*) good sludge test results by the above method, (*b*) poor sludge test results, and (*c*) intermediate test results. These banks of transformers will be started at various times during the coming year and it is hoped that by the time of the next Annual Meeting all these transformers will be under way and some preliminary test data will be available.

---

[2] See p. 969.

[3] Symposium on Plastics, Am. Soc. Testing Mats. (1944). (Symposium issued as separate publication, February, 1944.)

(*2*) *Resistivity and Power Factor.*—A proposed method for determination of resistivity and power factor of petroleum insulating oils has been developed and is undergoing further study. While it is not ready for publication as a tentative method, it is encouraging to note that progress has been made and that the subcommittee plans to submit it for publication during the coming year.

(*3*) *Gas Content of Insulating Oils.*—With last year's report there was published as information a Proposed Routine Method of Test for Gas Content of Insulating Oil. During the year comments have been received on this routine method. In addition, the subcommittee has developed a proposed referee method of test. The revised routine method and the referee test entitled Proposed Methods of Test for Gas Content of Insulating Oils[4] are published as information in Appendix III to elicit further criticism and suggestions.

(*4*) *Dielectric Strength.*—During the past nine years Subcommittee IV, in its Section on Dielectric Strength, has made very exhaustive studies of this test. A great deal of this work was carried on during the time when E. J. Rutan was chairman of this section (from March, 1935, until June, 1943). The data accumulated during this period have been compiled for publication and appear in Appendix II because it is felt that this information should be a matter of permanent record.

In the tentative revision of the dielectric strength test in the Standard Methods of Testing Electrical Insulating Oils (D 117 – 43), as published in 1943, there is no section on Preparation of Sample. There was such a section in the tentative revision as published in 1942, but because of numerous objections it was deleted by letter ballot vote. Subcommittee IV has now prepared a new description on Preparation of Sample which has been approved by Committee D-9, and is recommended for inclusion in the tentative revision as a new Section 26, the subsequent sections to be numbered accordingly. Numerous other parts of this tentative revision have been under study during the past year and it is expected that during the coming year some further changes will be recommended.

(*5*) *Method of Test for Askarels.*—During the year Subcommittee IV unfortunately lost the services of Karl Horine because of his retirement. Mr. Horine's section had prepared the Proposed Methods of Testing Askarels which were published as information last year with the Report of Committee D-9. R. W. Chadbourn has been appointed as the new chairman of this section and during the coming year the section plans to revise the methods, in the light of comments and suggestions that have been received, and to include a method for the determination of dielectric strength looking toward submittal of the complete methods to the Society for publication as tentative.

(*6*) *Significance of Tests.*—Subcommittee IV has now prepared statements covering the significance of the following tests when applied to insulating oils:

1. Color,
2. Neutralization number,
3. Dielectric strength,

---

[4] See p. 450.

4. Mineral acids,
5. Pour test,
6. Flash point,
7. Specific gravity,
8. Free and corrosive sulfur,
9. Viscosity,
10. Free chlorides, and
11. Sludge tests.

These have been submitted by Subcommittee XI to Committee D-9 for final action.

(7) *Water in Insulating Oils.*—Work directed toward the development of a standard method of test to determine the actual percentages of small traces of moisture in insulating oils is still under study. Various tests are being investigated and cooperative test samples are being distributed for test. It is hoped that during the coming year the committee may be able to prepare a proposed method or several alternative proposed methods which can be published as information and for further study.

(8) *Storage of Used Oils.*—During the past two years A. E. Flowers has presented to the committee several papers on the effect of storage conditions on the properties of used transformer oils. These papers have been under study by Subcommittee IV and will receive further attention during the coming year.

Subcommittee V on Ceramic Products (L. J. Cavanaugh, chairman).—Progress has been made in the studies relating to the development of test methods for high dielectric constant materials.

The Tentative Specifications for Low and Medium Voltage Pin-Type Lime-Glass Insulators (D 730 - 43 T) were prepared by this subcommittee.

An alternate method of test for thermal shock of pin-type lime-glass insulators[2] was recently accepted for publication as a tentative revision of Standard Methods D 468. This is based on the use of the Preston Machine and is discussed in a paper by K. C. Lyon and R. F. Scott.[5]

Progress has been made in the preparation of specifications for lime-glass communication insulators. It is planned to submit these for publication as an emergency standard.

As a result of action taken by this subcommittee, Committee D-9 is recommending that the tentative revision of the Standard Methods of Testing Electrical Porcelain (D 116 - 42) relating to the dye penetration test, the Tentative Methods of Testing Glass Spool Insulators (D 550 - 41 T), and the Tentative Methods of Testing Steatite Used as Electrical Insulation (D 667 - 42 T) be adopted as standard.

Subcommittee VI on Solid Filling and Treating Compounds (R. H. Titley, chairman).—The Section on Oil Solubility of Solid Filling and Treating Compounds has no recommendation to make at this time and reports progress on the work under way.

Considerable work has been done during the past year relative to test methods for waxes. Further meetings with manufacturers of waxes are to be held to ascertain whether or not additional test methods are desirable. It is planned to recommend the addition of these test procedures to the Tentative Methods of Testing Solid Filling and Treating Compounds Used for Electrical Insulation (D 176 - 42 T) after they have been approved by the members of Subcommittee VI. Specifications for waxes are also being formulated and will be offered to Committee D-9 for consideration as soon as practicable.

Statements on significance of tests have been prepared and circulated among the members of Subcommittee VI.

---

[5] K. C. Lyon and R. F. Scott, "Thermal Shock Testing of Lime Glass Insulators by A.S.T.M. Method D 468 *versus* the Preston Apparatus (A.S.T.M. Method C 149)," compilation of "A.S.T.M. Standards on Electrical Insulating Materials," p. 469 (1944).

The returns on the latest revision indicate that a majority of the members consider the present draft satisfactory and it will accordingly be presented to Subcommittee XI for approval before the summer meeting.

At the meeting in Philadelphia it was decided to form a section to draft specifications for solid filling and treating compounds.

Subcommittee VII on Insulating Fabrics (R. W. Chadbourn, chairman).—Several problems involving varnished cambric tapes are now under active consideration by this subcommittee. These include: (*1*) Revising the present elongation – dielectric strength requirements to approximate more closely conditions of service, (*2*) possible substitution of standard humidity requirements for conditioning in place of the present 60 to 65 per cent, (*3*) further study of an alternative power factor test method which will eliminate vacuum treatment, (*4*) revision of the sampling procedure to make the number of rolls to be tested more nearly proportional to the yardage purchased and (*5*) stiffening the rejection requirements in the specifications.

The first of these problems has required extensive round-robin investigation by many laboratories. So far as known, the subcommittee has made the first successful effort to find out just what happens to tape under service conditions, and the problem has now resolved itself into an attempt (*1*) to devise a simple test method that will simulate, as closely as practicable, the widely varying conditions of use, and (*2*) to determine suitable specification limits for such an approximate method. What is hoped will be the final series of tests in this investigation is now under way.

Significance of test statements have now been written for most of the tests on varnished cloth tapes.

It is proposed to substitute the term "treated sleeving" for "varnished tubing" in the Standard Methods of Testing Flexible Varnished Tubing (D 350 – 43) and in the Tentative Specifications for Flexible Varnished Tubing (D 372–40 T) and to enlarge the scope of the former to include fiberglass and rayon as well as cotton base. Specifications will be written for fiberglass-base sleeving as soon as possible.

The section studying treated glass fabrics has a number of problems under consideration.

Subcommittee VIII on Insulating Paper (C. T. Hatcher, chairman).—The joint committee consisting of members of Committee D-6 on Paper and Paper Products and Committee D-9 has been continuing the study in connection with developing a pH method for acidity determination of papers. A method has been agreed upon for conducting round-robin tests for determining the reproducibility of the method. Samples of several types of papers have been submitted to the laboratories participating in the test and data from these tests are expected in the near future.

The Sections on Physical Tests and Mechanical Tests are following closely the methods of Committee D-6 for performing these tests on the basis that they will be used wherever possible. The D-6 Method of Test for Moisture in Paper, Paperboard, and Paperboard and Fiberboard Containers (D 644 – 42 T) has been approved for inclusion in the Tentative Methods of Sampling and Testing Untreated Paper Used in Electrical Insulation (D 202 – 41 T) in place of the existing method with the exception that the provisions for sampling in Methods D 202 be retained. The D-6 Method of Test for Internal Tearing Resistance of Paper (D 689 – 42 T) has been approved for inclusion in Tentative Methods D 202 in place of the present tearing strength method with the exception that the sampling and conditioning directions in Methods D 202 shall be followed. The D-6 Methods of Test for Folding Endurance of Paper (D 643 – 43) have been approved for inclusion in Methods D 202 in place of the existing method with the exception that the sampling and conditioning directions in Methods D 202 shall be followed and method B be used. The bursting strength method, air resistance method, and sampling and weight methods of Committee D-6 are being studied for inclusion, or modification for inclusion, in Methods D 202.

A change in the formula for expressing apparent density has been approved. The formula as it now appears in Methods D 202 is $D = \frac{W}{T} \times 0.0001001$. The approved change is to have the formula read $D = \frac{W}{T} \times 0.0000394$ and changing the definition of T to read "thickness of the specimen in inches." This change eliminates the last three figures in the formula, namely, 001 as it is felt that these places are not significant inasmuch as at least the thickness measurements involved are not reproducible to so precise a degree. The thickness definition was changed to inches as this is the normal measurement made and the necessary conversion factor from centimeters to inches was used in the formula.

The penetration test method in Methods D 202 is being reviewed as it appears that the formula now being used does not give values which are accurate for comparison of papers of different thicknesses, penetrabilities, etc. Since the use of the present method is questionable for obtaining comparative results on different papers, consideration is being given to changing the method for calculating absorbency.

The Section on Significance of Tests is working on statements for the various tests included in Methods D 202. Three statements have been prepared and submitted to the Subcommittee on Significance of Tests for consideration.

Subcommittee IX on Mica Products (E. O. Hausmann, chairman).—The project of preparing colored transparencies to be used for quality classification of natural mica is being continued. The first transparency plate has been received from the photographer and further work is continuing, preliminary to distribution of the plate with proper viewing equipment to the members of the subcommittee for comment.

A revision of the Standard Methods of Test for Grading and Classification of Natural Mica (D 351 – 38) has been recommended to include a quality classification chart of Muscovite block mica 0.007 to 0.030 in. thick based on visual judgment. This chart is being added to Methods D 351 in order to further clarify Table I on classification of quality of mica. Other minor revisions in Methods D 351 are under consideration.

Tentative Specifications for Natural Block Mica and Mica Films Suitable for Use in Fixed Mica-Dielectric Capacitors (D 748 – 43 T) have been issued. Specifications for mica, both natural and bonded, for other applications are under consideration.

Subcommittee X on Conditioning (Robert Burns, chairman).—Tentative Specifications for Enclosures for Small Testing Machines for Tests at Subnormal and Supernormal Temperatures of Electrical Insulating Materials and Plastics (D 760 – 44 T) and for Servicing Units for Tests at Subnormal and Supernormal Temperatures of Electrical Insulating Materials and Plastics (D 761 – 44 T) were prepared by the subcommittee and approved by the Society during the year. These cover equipment suitable for testing electrical insulating materials and plastics over the temperature range of -70 to $+170$ F. for use by those not equipped with suitable walk-in equipment. Specifications D 761 cover a device which delivers low and high temperatures to any laboratory-built, suitably insulated enclosure for use on conventional testing machines as well as on the specific enclosure described in Specifications D 760.

Laboratory investigations are being conducted looking toward revising the Tentative Methods of Conditioning Plastics and Electrical Insulating Materials for Testing (D 618 - 41 T) to permit the classification of sheet materials too thin for classification by Izod impact. The preliminary studies included stiffness and tension impact, and the results indicated that a less rigid system of classification might be feasible for tests other than impact.

The question of establishing standard testing temperatures over a reasonably wide range has been studied. The subcommittee has approved by letter ballot -40, $+77$ and $+160$ F. on the basis that these three temperatures should suffice for the usual engineering evaluation of insulating materials and plastics but would not preclude testing at other temperatures for specific applications.

Subcommittee XI on Significance of Tests (H. L. Curtis, chairman).—Six statements of significance of tests for various materials have been submitted to the subcommittee and are being studied carefully.

Subcommittee XII on Electrical Tests (Gordon Thompson, chairman).—Insulation resistance, including absorption current variation with long periods of electrification, and power factor and dielectric constant of certain rutile bodies with very high dielectric constants have been studied during the past year. Errors due to parasitic effects at high frequencies are being investigated for certain measuring methods and equipment. Work is in progress looking toward a more exact definition of test conditions for the measurement of resistance of material to the electric arc.

Subcommittee XIII on Mechanical Tests (F. G. Tatnall, chairman).—This subcommittee, which is still in course of organization, will function as a correlating committee to review test methods developed in the various subcommittees for the purpose of eliminating any discrepancies in procedures. The membership is being organized into sections to carry on this work.

The present officers of the committee have been re-elected for the ensuing term of two years.

This report has been submitted to letter ballot of the committee which consists of 101 voting members; 81 members returned their ballots, of whom 73 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the committee,

MYRON P. DAVIS,
Chairman.

W. A. EVANS,
Vice-Chairman.

W. A. ZINZOW,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-9 presented to the Society through Committee E-10 on Standards the following recommendations:

Emergency Specifications for:

Communication and Signal Pin-Type Lime-Glass Insulators (ES - 41),

Revision of Tentative Specifications for:

Laminated Thermosetting Materials (D 709 - 43 T), recommended jointly by Committee D-9 and Committee D-20 on Plastics,
Flexible Varnished Tubing Used in Electrical Insulation (D 372 - 40 T),
Black Bias-Cut Varnished Cloth Tape Used for Electrical Insulation (D 373 - 39 T),

Revision of Tentative Methods of:

Test for Power Factor and Dielectric Constant of Electrical Insulating Materials (D 150 - 44 T),
Testing Varnished Cloths and Varnished Cloth Tapes Used in Electrical Insulation (D 295 - 43 T),

Tentative Revision of Standard Methods of:

Testing Flexible Varnished Tubing Used for Electrical Insulation (D 350 - 43), and
Testing Sheet and Plate Materials Used in Electrical Insulation (D 229 - 43).

The emergency standard was accepted by Committee E-10 on August 28, 1944, the revision of Tentative Specifications D 709 on December 11, 1944, and the remainder of the recommendations on December 22, 1944. The emergency specifications, the revised tentatives, and the tentative revisions appear in the 1944 Book of A.S.T.M. Standards, Part III.

On January 9, 1945, the Standards Committee accepted the joint recommendation of Committee D-9 and Committee D-20 on Plastics that the Tentative Methods of Conditioning Plastics and Electrical Insulating Materials for Testing (D 618 - 44 T) be revised. The revised tentative methods also appear in the 1944 Book of A.S.T.M. Standards, Part III.

APPENDIX I

RECOMMENDATIONS AFFECTING STANDARDS FOR ELECTRICAL INSULATING MATERIALS

In this Appendix are given recommendations affecting certain standards and tentative standards covering electrical insulating materials which are referred to earlier in the report.[1] The standards and tentative standards appear in their present form in either the 1942 Book of A.S.T.M. Standards, Part III, or the 1943 Supplement, Part III, as indicated by the final number in the A.S.T.M. designation.

NEW TENTATIVE STANDARDS

Tentative Specifications for Orange Shellac and Other Indian Lacs for Electrical Insulation:[2]

These specifications outline the requirements for five grades of lacs differing somewhat from the requirements of the lacs covered by the Standard Specifications for Orange Shellac (D 237 – 43 T). It is recommended that these specifications be accepted for publication as tentative.

Tentative Method of Flexural Test of Plastics:[2]

These methods have been developed jointly by subcommittees of Committee D-9 and Committee D-20 on Plastics. It is recommended that they be accepted for publication as tentative.

REVISIONS OF TENTATIVE STANDARDS

Tentative Methods of Test for Power Factor and Dielectric Constant of Electrical Insulating Materials (D 150 – 42 T):[3]

This revision consists of the addition of the following new definition to Section 2, relettering present Paragraph (*e*) as (*f*):

> (*e*) *Dielectric Dissipation Factor.*—The dielectric dissipation factor is the term used to designate the tangent of the dielectric loss angle. It is usually represented in mathematical equations by the symbol D.

Tentative Methods of Sampling and Testing Untreated Paper Used in Electrical Insulation (D 202 – 41 T):

Revisions in these methods consist of the deletion of detailed descriptions of three methods of test for moisture content, tearing strength, and folding endurance and substituting therefor reference paragraphs to available A.S.T.M. test methods for these particular tests. Also a minor revision in Section 15 on apparent density in which the formula is changed by changing the constants in such a manner that the dimensions are given in inches rather than centimeters as was formerly the case. Another minor correction in the formula drops a figure in the seventh decimal place since it is not significant.

---

[1] See p. 422.

[2] 1944 Book of A.S.T.M. Standards, Part III.

[3] See Editorial Note, p. 431.

Sections 4 to 7.—Replace the test for moisture content in these sections by the following:

3. *Moisture Content.*—Moisture content shall be determined in accordance with the Tentative Method of Test for Moisture in Paper, Paperboard, and Paperboard and Fiberboard Containers (A.S.T.M. Designation: D 644), except that the material shall be sampled in accordance with Section 2 of Methods D 202.

Section 15.—Change the formula in this section from "$D = \frac{W}{T} \times 0.0001001$" to read "$D = \frac{W}{T} \times 0.0000394$;" and change the definition of T to: "thickness of the specimen in inches."

Sections 20 to 23.—Replace the test for tearing strength in these sections by the following:

Tearing Strength.—Tearing strength shall be determined in accordance with the Tentative Method of Test for Internal Tearing Resistance of Paper (A.S.T.M. Designation: D 689), except that the material shall be sampled and conditioned in accordance with Sections 2 and 3 of Methods D 202.

Sections 28 to 32.—Replace the test for folding endurance in these sections by the following:

Folding Endurance.—Folding endurance shall be determined in accordance with Method B in the Standard Methods of Test for Folding Endurance of Paper (A.S.T.M. Designation: D 643), except that the material shall be sampled and conditioned in accordance with Sections 2 and 3 of Methods D 202.

Tentative Specifications for Phenolic Laminated Sheet for Radio Applications (D 467 – 40 T):

This revision in these specifications involves the deletion of requirements for a class of material which is not being generally produced and for which there is no consumer demand.

Grade 6.—Throughout the specifications delete all references and requirements for grade 6 which appear in Section 1 and in Tables I, II, V, VI, and VII, and the Appendix.

Tentative Methods of Conditioning Plastics and Electrical Insulating Materials for Testing (D 618 – 41 T):

This revision involves a change in the time of cooling required after conditioning before the specimens are tested. The time of cooling is reduced from 16 hr. to 3 hr. unless the materials are known to require substantial time to attain essential stability of the property being tested.

Section 4(a).—Change to read as follows by the addition of the italicized word and figures and the omission of the figure in brackets:

4.(*a*) Type S Materials.—Type S specimens shall be conditioned for a period of 48 hr. in the circulation air oven at a temperature of 50 ± 3 C. (122 ± 5.4 F.). The specimens shall be removed from the oven *and* cooled in the desiccator over anhydrous calcium chloride for a period of at least [16] *3* hr. prior to actual testing. *In the case of materials which are known or are expected to require substantial time to attain essential stability of the property being measured, the cooling period shall be at least 16 hr.* A definite time interval, previously decided upon by the cooperating laboratories, shall be allowed to elapse between the removal of the specimens from the desiccator and the application of the tests. The tests may be made at room atmospheric conditions.

Method of Test for Distortion Under Heat of Molded Electrical Insulating Materials (D 648 – 41 T):

Committee D-9 joins with Committee D-20 on Plastics in recommending revision of this method to be issued under the title "Tentative Method of Test for Heat Distortion Temperature of Plastics."[4]

TENTATIVE REVISIONS OF STANDARDS

Standard Methods of Testing Electrical Insulating Oils (D 117 – 43):

Last year a change was made in the

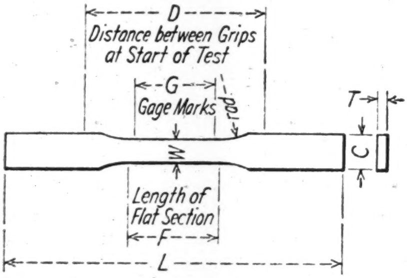
---

[4] This method was accepted as tentative by the Society and appears in the 1944 Book of A.S.T.M. Standards, Part III.

tentative revision of D 117 – 42 which deleted from the tentative revision Section 26 containing a description of the procedure for preparation of the sample. A new Section 26 has now been prepared to replace this deleted section. It is therefore recommended that this change, as given below, in the tentative revision[5] be made and that the revised tentative revision be continued as tentative:

Section 26.—Revise the tentative revision referred to above by inserting the following as a new Section 26, and renumbering the subsequent sections accordingly:

26. *Preparation of Sample.*—The dielectric strength of liquid dielectrics may be markedly altered by the migration of impurities through the liquid. In order that representative test specimens may be obtained, the container shall be gently tilted or inverted and the oil swirled several times in such a way that any impurities present will be thoroughly mixed with the dielectric. Too rapid agitation is undesirable, as it introduces an excessive amount of air into the mixture. Immediately after mixing, the test cup shall be filled with liquid to a height of not less than 20 mm. (0.787 in.) above the top of the electrodes. In order that entrapped air may escape, the container shall be gently rocked a few times and the liquid allowed to stand in the cup for 3 min. before voltage is applied. Where more than one test is made on the same specimen, the liquid shall be allowed to stand for 1 min. between tests.



Dimension, in.	T-Thickness,[a] in.					Tolerances, in.
	¼ in. or under		Over ¼ to ½ in., Incl.		Over ½ to 1 in., Incl.[b]	
	Type I	Type II[c]	Type I	Type II[c]	Type I	
C—Width overall	0.750	0.750	1.125	1.125	1.500	±0.016
W—Width of flat section	0.500	0.250	0.750	0.375	1.000	−0.000 +0.005
F—Length of flat section	2.25	2.25	2.25	2.25	2.25	±0.016
G—Gage length[d]	2.00	2.00	2.00	2.00	2.00	±0.016
D—Distance between grips[d]	4½	5¼	4½	5¼	5½	±⅛
L—Length overall	8½	9⅝	9¾	10⅛	12	minimum

[a] Tolerance on thickness shall be the standard for the grade of material tested.

[b] For sheets of a nominal thickness over 1 in. the specimens shall be machined to 1.000 ± 0.010 in. in thickness. For thicknesses between 1 and 2 in. approximately equal amounts shall be machined from each surface. For thicker sheets both surfaces shall be machined and the location of the specimen with reference to the original thickness shall be noted.

[c] The type II specimen shall be used for material from which the type I specimen does not give satisfactory failures in the gage length, such as for resin-impregnated compressed laminated wood.

[d] Test marks only.

FIG. 1.—Tension Test Specimen for Sheet and Plate Insulating Materials.

Standard Methods of Testing Sheet and Plate Materials Used in Electrical Insulation (D 229 – 43):

This test method has undergone considerable revision within the past two years to make it possible to correlate the methods of test prepared by Committee D-20 on Plastics for general use on all types of plastics as well as to correlate these methods with those outlined in Federal Specifications being prepared and revised. The revision of Section 6 (*a*) given below refers to the current tentative revision[6] of these methods.

---

[5] 1943 Supplement to Book of A.S.T.M. Standards, Part III, p. 531.

[6] 1943 Supplement to Book of A.S.T.M. Standards, Part III, p. 527.

The revision of Sections 30 (*b*) and 33 (*d*) concern a new type of test procedure to be used in making dielectric breakdown measurements when the voltage is applied parallel to laminations. The new procedure uses a smaller specimen and experience in the subcommittee presenting the revision indicates more satisfactory and reproducible results may be obtained.

The revision of Sections 39 to 42 concerns the deletion of the procedure for making Rockwell hardness tests and the replacement therefor of a new section referring to a new method developed jointly by Committee D-9 and Committee D-20.

Another tentative revision of this method concerns the addition of a new Section 51 referring to the Tentative Method of Test for Coefficient of Linear Thermal Expansion of Plastics (D 696 - 42 T) which has been found satisfactory for this type of material.

Section 6(a).—Delete the table shown with Fig. 1 of the current tentative revision[6] and substitute for it the following new table and notes showing dimensional requirements for two types of specimens as shown in the accompanying Fig. 1.

Section 30 (b).—Change from its present form: namely,

> (*b*) For tests parallel to the flat sides, the material shall be cut into sections 2-in. square. Holes shall be drilled into opposite edges of each section so as to line up with each other, the inner ends of the holes being $\frac{1}{2}$ in. apart. Metal electrodes shall be used, the ends of which exactly fit the ends of the holes. Thus, in effect, the material is tested edgewise in a modified needle gap. The diameter of the hole should be approximately one fourth the thickness of the specimen. For very thin specimens it may be necessary to use a larger ratio of drill size. Results shall be expressed in total kilovolts at breakdown.

to read as follows:

> (*b*) For tests parallel to the flat sides (parallel with laminations in laminated sheets) the test specimens shall be $\frac{1}{2}$ in. in width by 1 in. in length by the thickness of the material. Minimum thickness of material shall be $\frac{1}{8}$ in. A hole shall be drilled in the approximate center of the 1-in. length in a direction parallel with the flat sides, to a depth of $\frac{7}{16}$ in., leaving a thickness of $\frac{1}{16}$ in. to be tested. A snug fitting metal pin electrode, with the end ground to conform with the shape of the drill used, shall be inserted in the hole. The specimen shall be placed on a flat metal plate, which shall be at least $1\frac{1}{2}$ in. in diameter. This plate shall serve as the lower electrode. Thus, in effect, the material shall be tested parallel with the flat sides in a point-plane gap. The diameter of the hole shall be as shown in the following table:

Nominal Thickness of Sheets, in.	Nominal Hole Diameter for Pin Electrode, in.
$\frac{1}{8}$ to $\frac{1}{4}$, incl.	1/16
Over $\frac{1}{4}$	$\frac{1}{8}$

> NOTE.—For sheets with exceptionally high dielectric strength, surface flashover may occur. Such cases should be noted in the report.

Section 33 (d).—Change from its present form: namely,

> (*d*) At least five tests shall be made at each test temperature in the short-time method, and at least three tests in the step-by-step method. Where the range of test temperature is considerable, tests should be made at not less than four temperatures, so that a curve of dielectric strength against temperature may be plotted.

to read as follows:

> (*d*) At least five tests shall be made at each test temperature in the short-time method, and at least three tests in the step-by-step method. When the range of test temperatures is considerable, tests should be made at not less than four temperatures, if a curve of dielectric strength against temperature is desired.
>
> NOTE.—The thickness of the section shall be measured prior to breakdown. This can be conveniently done by measuring the length of the electrode, then the combined length of the specimen and electrode with the electrode inserted in place.

Sections 39 to 42.—Replace the test for Rockwell hardness in these sections by the following:

> 39. Rockwell hardness of all sheet and plate insulating materials shall be determined in ac-

cordance with the Tentative Method of Test for Rockwell Hardness of Plastics and Electrical Insulating Materials (A.S.T.M. Designation: D 785).[2]

Section 51.—Add a new Section 51 to read as follows:

51. *Coefficient of Linear Thermal Expansion.*—The coefficient of linear thermal expansion of all sheet and plate insulating materials shall be determined in accordance with the Tentative Method of Test for Coefficient of Linear Thermal Expansion of Plastics (A.S.T.M. Designation: D 696).

Standard Methods of Testing Laminated Tubes Used in Electrical Insulation (D 348 – 42):

This revision concerns the correlation of this method of test with the tensile strength test method developed in Committee D-20 on Plastics and tests used in Federal Specifications. The changes made involve a minor change in the dimensions of the test specimen and test specimen holder.

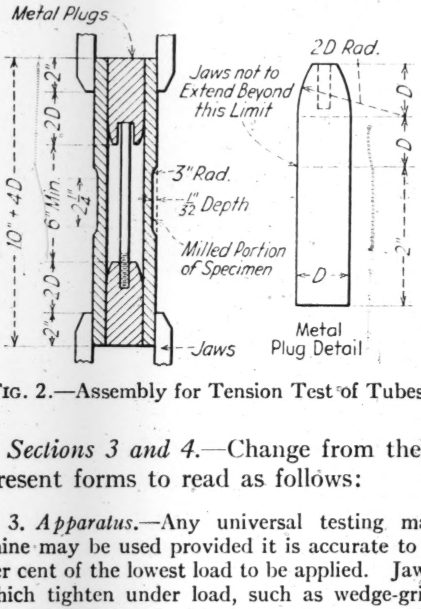


FIG. 2.—Assembly for Tension Test of Tubes.

Sections 3 and 4.—Change from their present forms to read as follows:

3. *Apparatus.*—Any universal testing machine may be used provided it is accurate to 1 per cent of the lowest load to be applied. Jaws which tighten under load, such as wedge-grip jaws, shall be used with the specimen properly aligned.

4. *Test Specimens.*—The length of the test specimens shall be 10 in. plus 4 times the inside diameter of the tube. When the wall thickness of the tubing is $\frac{1}{8}$ in. or over, a groove $2\frac{1}{4}$ in. in length in the flat portion and $\frac{1}{32}$ in. in depth shall be machined around the tube at the center with corners rounded to a radius of 3 in. Steel or brass plugs, whose length is 2 in. plus twice the diameter, and which conform to Fig. 1 (the accompanying Fig. 2) shall be used to plug the ends of the specimen to prevent crushing. The plugs shall fit the specimen within 0.010 in. They may be located conveniently in the tube by separating and supporting them on a metal rod the lower end of which is screwed into the lower plug and the upper end of which rests in a loose socket as shown.

Standard Methods of Testing Laminated Round Rods Used in Electrical Insulation (D 349 – 42):

This revision is similar to the revision recommended above in Methods D 348 – 42 as part of the correlation program between the D-9 methods, Methods D 638, and Federal Specifications LP-406. It involves a relatively minor change in the dimensions of the test specimen.

Section 4.—Change this section to read as follows by the addition of the italicized words and the omission of those in brackets:

4. The test specimens shall be about 12 in. in length. When the diameter of the rod is $\frac{1}{4}$ in. or over, a groove [1 in. in width] ***2.25 in. in length,*** and $\frac{1}{32}$ in. in depth with corners rounded to a radius of 3 in. shall be machined around the rod at the center.

Standard Methods of Test for Grading and Classification of Natural Mica (D 351 – 38):

This revision consists of the addition of a second table as a supplement to this method of test. The purpose of this table is to expand and clarify the present classifications of quality of mica as given in Table I. It does not supplant this table nor change the method in any way.

Table II.—Add as a supplement to this method the accompanying Table I.

ADOPTION OF TENTATIVE STANDARDS AS STANDARD

The committee recommends that the following eight tentative standards be approved for reference to letter ballot of the Society for adoption as standard without revision, except in the case of one method as indicated:

Tentative Methods of:

Test for Saponification Number of Petroleum Products by Color-Indicator Titration (D 94 – 43 T), with minor editorial revisions as given in the current Report of Committee D-2,[7]
Test for Dielectric Strength of Electrical Insulating Materials at Commercial Power Frequencies (D 149 – 40 T),
Testing Solid Filling and Treating Compounds Used for Electrical Insulation (D 176 – 42 T),
Testing Glass Spool Insulators (D 550 – 41 T),
Test for Punching Quality of Phenolic Laminated Sheets (D 617 – 41 T),
Test for Product Uniformity of Phenolic Laminated Sheets (D 634 – 41 T),
Testing Steatite Used as Electrical Insulation (D 667 – 42 T), and
Measuring Dimensions of Rigid Tubes Used in Electrical Insulation (D 668 – 42 T).

TABLE I.—QUALITY CLASSIFICATION OF NATURAL BLOCK MICA 0.007 TO 0.030 IN. IN THICKNESS BASED ON VISUAL JUDGMENT.

NOTE 1.—The visual properties of block mica usually are judged under the following light conditions:
For stains and inclusions—Transmitted daylight or equivalent.
For air inclusions—Reflected daylight or equivalent.
For waves, buckles, ridges, etc.—Reflected daylight through a window frame where distortion of parallel and vertical lines of reflected image can be judged.

NOTE 2.—The mechanical properties of block mica usually are judged as follows:
Hardness—As judged by sharp clear ring when mica is dropped on a hard surface.
Rigidity—Relative stiffness judged by flexing with fingers.

NOTE 3.—Heavy stained and black stained and spotted qualities are obtainable in hard and soft varieties and with or without conducting veins and spots.

NOTE 4.—Natural mica occurs in various colors which are more pronounced the thicker the block. Some typical colors are ruby, white, light green, green, rum, etc.

NOTE 5.—Quality of films less than 0.007 in. in thickness shall be visual equivalent of corresponding block.

Properties	Clear Uniform Color	Air Inclusions				Slight Stains (Color Variation)	Light Dotted	Light Spotted	Sooty Stains	Black Stained and Spotted	Red Stained and Spotted	Green Stained and Spotted	Clay Stained	Vegetable Stained	Mineral Inclusions			Waviness			Buckles, Ridges, Reaves, etc.	Rigid	Hardness			Cracks (Edge)
		None	Slight	Medium	Heavy										Slight	Medium	Heavy	Slight	Medium	Heavy			Hard	Slightly Soft	Soft	
Classifications:																										
Clear	√	√	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	√	√	X	X	X
Clear and Slightly Stained	√	√	√	X	X	X*	X	X	X	X	X	X	X	X	X	X	X	√	X	X	X	√	√	X	X	X
Fair Stained	√	√	√	√	X	√	X	X	X	X	X	X	X	X	X	X	X	√	√	X	X	√	√	X	X	X
Good Stained	√	√	√	√	X	√	X	X	X	X	X	X	X	√	√	X	X	√	√	√	X	√	√	X	X	X
Stained A	√	√	√	√	√	√	X	X	X	X	X	X	√	√	√	X	X	√	√	√	√	√	√	√	X	√
Stained B	√	√	√	√	√	√	X	X	X	X	X	X	√	√	√	√	X	√	√	√	√	√	√	√	X	√
Heavy Stained	√	√	√	√	√	√	X	X	√	X	X	X	√	√	√	√	√	√	√	√	√	√	√	√	X	√
Black Stained and Spotted	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√

√ = permissible.
X = not permissible.
* Except in regions adjacent to edge.

ADOPTION OF TENTATIVE REVISION OF STANDARD AS STANDARD

Standard Methods of Testing Electrical Porcelain (D 116 – 42):

The committee recommends that the tentative revision[8] of these methods as submitted in June, 1942, and which refers to a procedure for determining the porosity of porcelain by the dye penetration method be approved for reference to letter ballot of the Society for adoption as standard.

---

[7] See Report of Committee D-2 on Petroleum Products and Lubricants, p. 378.

[8] 1943 Supplement to Book of A.S.T.M. Standards Part III, p. 533.

Standard Methods of Testing Shellac Used for Electrical Insulation (D 411 – 42):

The committee recommends that the tentative revision[9] of these methods as submitted in June, 1942, and which provides for a change in the requirements for the test specimen in Section 11 (*a*) be approved for reference to letter ballot of the Society for adoption as standard.

WITHDRAWAL OF TENTATIVE STANDARD

Tentative Method of Test for Comparing Thermal Conductivities of Solid Electrical Insulating Materials (D 325 – 31 T):

This tentative method has been carried as a comparative method for a large number of years without change or use so far as can be ascertained. During that time the Tentative Method of Test for Thermal Conductivity of Materials by Means of the Guarded Hot Plate (C 177 – 42 T) which provides procedures for measuring the thermal conductivities of a wider range of material has been prepared. Since the newer method gives more fundamental values not based on a standard material which may or may not be variable this method has become obsolete. The committee accordingly recommends that Method D 325 – 31 T be withdrawn

---

[9] 1943 Supplement to of Book A.S.T.M. Standards, Part III, p. 527.

APPENDIX II

INVESTIGATION OF TEST PROCEDURES FOR DIELECTRIC STRENGTH OF LIQUID INSULATION

REPORT OF SECTION L OF SUBCOMMITTEE IV ON WORK PERFORMED FROM 1935 TO 1941 ON DIELECTRIC STRENGTH OF LIQUID INSULATION

Published for information only.

The American Society for Testing Materials first accepted a method for dielectric strength tests of insulating oils in 1921 which was published in the Tentative Methods of Testing Transformer and Switch Oils (D 117 – 21 T) This method was prepared subsequent to an investigation by three cooperating laboratories, each of which tested 144 samples of oil. Part of this investigation was devoted to comparisons of the sphere and disk electrodes. These studies were reported in 1921.[1]

Between 1921 and 1935, a number of questions had arisen regarding certain features of the dielectric strength test. At the meeting of Committee D-9 held in March, 1935, Section L on Dielectric Strength, of Subcommittee IV on Liquid Insulation, was appointed to review the test procedure for dielectric strength of insulating oils in the then current A.S.T.M. Methods of Testing Electrical Insulating Oils (D 117 – 33)[2] and to suggest improvements. E. J. Rutan was appointed chairman of the section including the following membership, which is about the same personnel as now serving on the section, except for the present chairman:

E. J. Rutan *Chairman*
H. A. Ambrose
R. W. Chadbourn
F. M. Clark
E. C. De Baene
A. E. Flowers
M. Guarnier
O. A. Knapp
A. E. Maibauer
S. J. Rosch
M. F. Skinker
L. Stiles, Jr.

The results of the work of this section have been prepared for publication since it is thought that they represent the most extensive summary of dielectric strength data ever compiled for committee work.

Some of the more important questions studied were as follows:

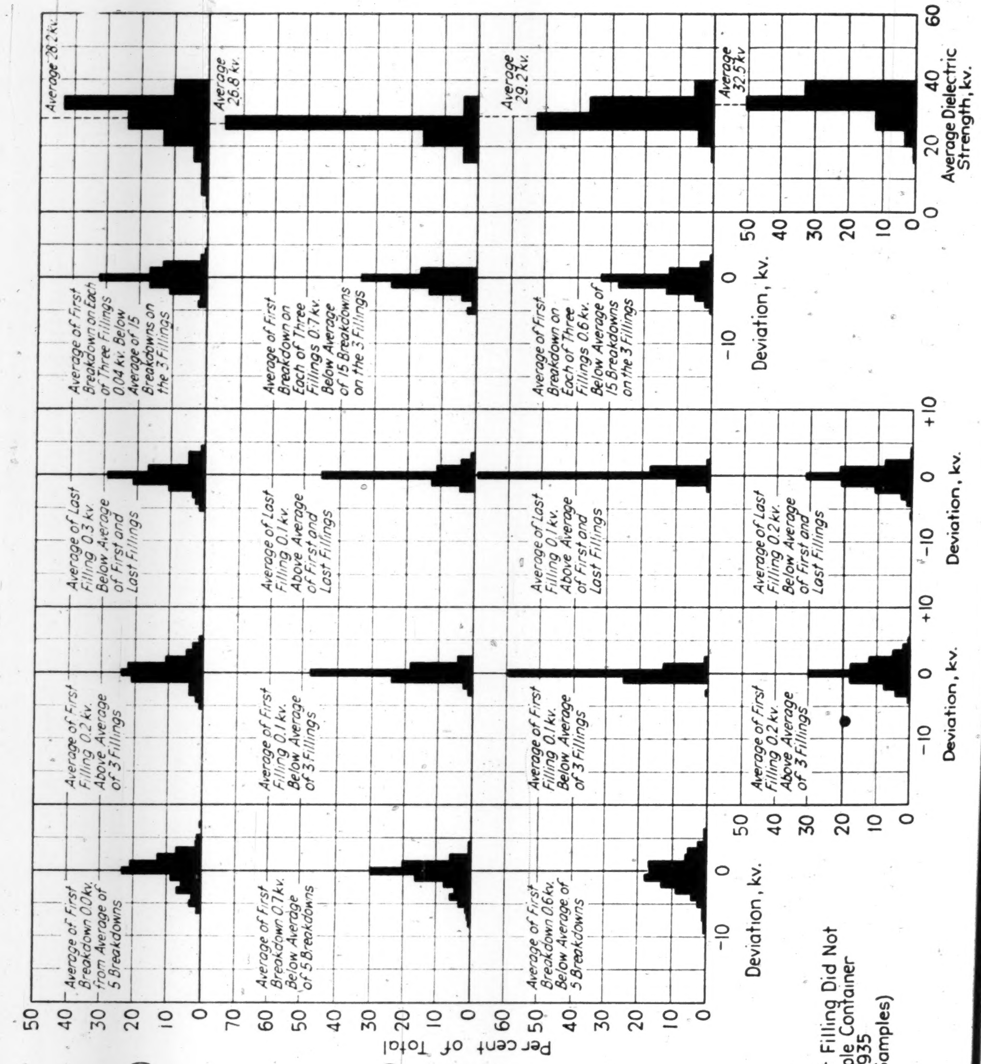
1. A more specific description of the testing equipment, particularly the transformer, the control, the method of measuring the voltage, and the method of cleaning the test cup were needed.
2. The need for a classification test in addition to the referee test due to the fact that many laboratories were using an abbreviated form of the A.S.T.M. method for maintenance and control testing.
3. Whether the dielectric strength differed between fillings from the top, middle, and one which drained the sample container.
4. What is a reasonable statement of the reproducibility of results?
5. Is the rate of rise of voltage of 3 kv. per sec. necessary and do available instruments give reliable indication at this rate?
6. Is there a basis for neglecting the momentary discharges as provided for in the method?
7. Is there a better shape of test electrode than the disk with square edges?
8. Clarification of the section dealing with mixing the sample before test.
9. Is there a detrimental effect due to taking five breakdowns on each filling? Are fast interrupting circuit breakers necessary?

A number of laboratories submitted detailed descriptions of their apparatus and testing procedure. Many of these laboratories also submitted data which they obtained during regular oil testing or on special tests. There was thus made available data on approximately 5000 samples of oil which in the opinion

---

[1] Joint Comparative Tests of Spark Gaps for Testing Transformer Oils, Appendix I, Report of Committee D-9 on Electrical Insulating Materials, *Proceedings*, Am. Soc. Testing Mats., Vol. 21, Part I, p. 396 (1921).

[2] 1933 Book of A.S.T.M. Standards, Part II, p. 1087.


Member A
1937
(98 Samples)
Member B
1937
(70 Samples)
Member C
1937
(160 Samples)
Member D
Used Oil - Last Filling Did Not Drain Sample Container
1935
(200 Samples)
Per cent of Total
Average of First Breakdown 0.0 kv. from Average of 5 Breakdowns
Average of First Filling 0.2 kv. Above Average of 3 Fillings
Average of Last Filling 0.3 kv. Below Average of First and Last Fillings
Average of First Breakdown on Each of Three Fillings 0.04 kv. Below Average of 15 Breakdowns on the 3 Fillings
Average 28.2 kv.
Average of First Breakdown 0.7 kv. Below Average of 5 Breakdowns
Average of First Filling 0.1 kv. Below Average of 3 Fillings
Average of Last Filling 0.1 kv. Above Average of First and Last Fillings
Average of First Breakdown on Each of Three Fillings 0.7 kv. Below Average of 15 Breakdowns on the 3 Fillings
Average 26.8 kv.
Average of First Breakdown 0.6 kv. Below Average of 5 Breakdowns
Average of First Filling 0.1 kv. Below Average of 3 Fillings
Average of Last Filling 0.1 kv. Above Average of First and Last Fillings
Average of First Breakdown on Each of Three Fillings 0.6 kv. Below Average of 15 Breakdowns on the 3 Fillings
Average 29.2 kv.
Average of First Filling 0.2 kv. Above Average of 3 Fillings
Average of Last Filling 0.2 kv. Below Average of First and Last Fillings
Average 32.5 kv
0
10
20
30
40
50
60
70
-10
+10
Deviation, kv.
Average Dielectric Strength, kv.

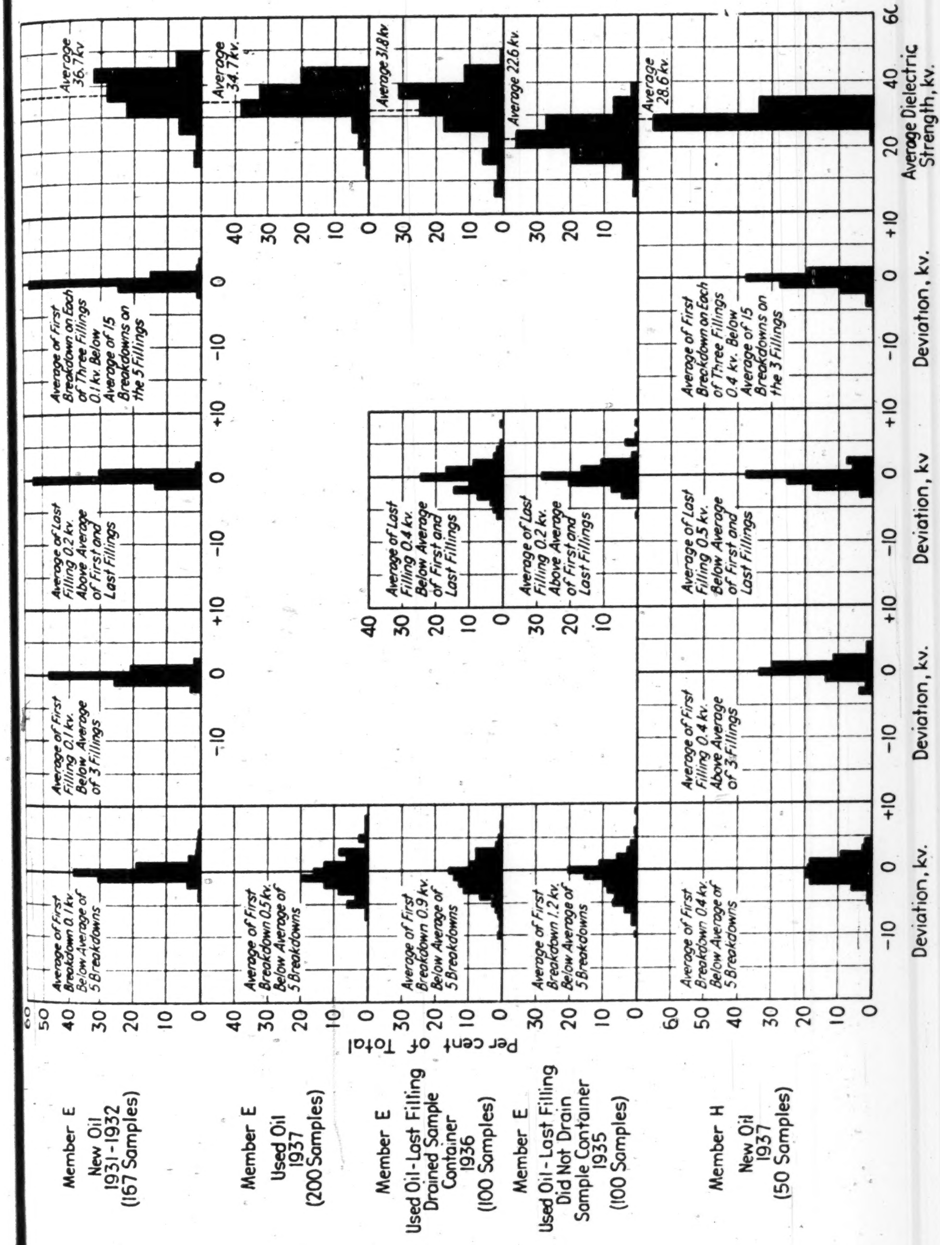


FIG. 1.—Dielectric Strength Tests on Insulating Oils.

NOTE.—Five breakdowns per filling in all cases. Rate of rise of voltage 3 kv. per sec.

TABLE I.—SUMMARY OF INFORMATION CONCERNING TEST PROCEDURE AND APPARATUS FOR DIELECTRIC STRENGTH TESTS OF INSULATING FLUIDS.

Cooperating Laboratory	Rate of Rise of Voltage, kv. per sec.	Rating of Test Transformer, kva.	Short-Circuit Current, ma.					Duration of Arc Current, sec.					Method of Opening Test Set Circuit	Cup Cleaning Fluid	Frequency of Cleaning Cup	Method of Setting Test Cup Gap	Cup Shaken Between Breakdown Tests	Method of Agitating Sample in Container Before Pouring into Test Cup
			20 kv.	30 kv.	31 kv.	34.5 kv.	40 kv.	20 kv.	30 kv.	31 kv.	34.5 kv.	40 kv.						
Detroit Edison Co.	3	3	...	...	265	325	...	...	...	0.033	0.033	...	automatic	benzol	each sample	pin gage	yes[b]	inverting
Standard Oil Co. of N. J.	3	3	...	...	...	...	...	...	...	...	...	...	automatic	sample	each sample	flat steel spacer 0.100 in.	no	inverting
The Texas Co.	3	2	...	...	...	...	...	...	...	...	...	...	automatic	gasoline and sample	twice a week with gasoline	pin gage	no	inverting
Brooklyn Edison Co., Inc.	3	3	210	305	315	350	405	...	...	...	...	...	automatic	gasoline	each sample	pin gage	yes	inverting
Consolidated Edison Co. of N. Y. Inc.	3	0.8 to 2.0[a]	35	50	...	...	65	...	...	...	...	...	automatic	carbon tetrachloride	once a day or more	go and no-go gage	no	inverting[c]
DeLaval Separator Co.	3	2	100	66	...	...	50	...	...	...	...	...	automatic	varnolene	after 3 fillings	go and no-go gage	yes	shaking
Hydro-Electric Power Commission of Ontario	6.65	5	17	28	...	...	55	no trip	0.84	...	...	0	automatic	sample	flushed after each test	go 0.1-in. diameter bar	yes	not agitated
Socony-Vacuum Oil Co., Inc.	3	4	...	...	...	...	...	...	...	...	...	...	automatic	new oil	each sample	round gage 0.100-in. diameter	yes	inverting
General Electric Co.	1.5	5	...	...	...	...	...	...	...	...	...	...	automatic	solvatone	several times per day	pin gage	no	inverting
Commonwealth Edison Co.	3	3	...	...	...	...	...	...	...	...	...	...	automatic	...	...	...	...	shaking
A.S.T.M. Methods D 117-33	3	2 min.	...	...	...	...	...	...	...	...	...	...	immediately after breakdown	gasoline	...	round gage 0.100-in. diameter	yes	shaking

---

[a] This is a potential transformer rated at 440 v-amp.

[b] Clean wire is also passed through gap between breakdowns.

[c] If water is suspected to be present, sample container is shaken vigorously and allowed to stand for 15 min. then inverted three times before testing.

of Section L represents the greatest collection of data ever assembled on the study of dielectric strength tests of insulating oil. This report has been prepared from that information.

Test Apparatus:

A study of the test apparatus and procedure given in Table I together with the apparatus specified in the Tentative Methods of Test for Dielectric Strength of Electrical Insulating Materials at Commercial Power Frequencies (A.S. T.M. Designation: D 149)[3] and the Measurement of Test Voltage in Dielectric Tests (A.I.E.E. Standard No. 4) resulted in the approval in 1940 of a tentative revision to A.S.T.M. Methods D 117 specifying the test apparatus and the preparation of the test cup.[4]

Number of Tests and Fillings:

In order to obtain an answer for items 2 and 3 above the data for 1100 samples (2835 cup fillings) were compiled and plotted in various groups as shown on Fig. 1. These data were obtained from six laboratories each using the equipment described in Table I and following the procedure described in A.S.T.M. Method D 117 - 33.[2] From the various groups on Fig. 1 the following conclusions were drawn:

(*a*) From the histograms in Group I it may be seen that the first dielectric breakdown of a filling oil tends to be lower than the average of five breakdowns. It may also be noted that for oils in service deviations of more than 2 kv. occur quite frequently. These results indicated that only one breakdown on a sample would not give reliable data.

(*b*) Group II is a comparison of the average of the five breakdowns on the first filling with the average of three fillings from the same sample and shows more reliability than Group I. The relation between the average of the first breakdown on each of three fillings and the average of all 15 breakdowns on the three fillings is given in Group IV and shows reasonable promise but the spread was not as narrow as in Group II. It was decided to adopt five breakdowns on one filling as a classification test because with this procedure there would usually be sufficient oil for additional fillings if check tests were desired.

(*c*) In Group III the results of the first filling are compared with the last filling of the same sample both when the last filling drained and did not drain the sample container. There is no marked difference in the deviation patterns and it was concluded that this precaution was not needed in the revised method of test.

Reproducibility of Results:

Group II on Fig. 1 represents the results of tests on 745 samples of new and used oil. An analysis of the deviation of the first filling of a sample from the average of three fillings on the same sample is as follows:

100 per cent of first fillings were within 5 kv. of average of 3 fillings
99.6 per cent of first fillings were within 4 kv. of average of 3 fillings
98.1 per cent of first fillings were within 3 kv. of average of 3 fillings
93.7 per cent of first fillings were within 2 kv. of average of 3 fillings
83.1 per cent of first fillings were within 1 kv. of average of 3 fillings

These results show that over 98 per cent of the first fillings were within 3 kv. of the average of 3 fillings and this value should be taken into consideration in establishing a standard value for classification tests.

In addition to the data summarized in Fig. 1, special tests were made on approximately 4000 samples by a few of the participating members. The data from these tests were used to study the effect of rate of voltage rise, instrument accuracy, momentary discharges, electrode shape, shaking the sample, and duration of arc current.

---

[3] 1942 Book of A.S.T.M. Standards, Part III, p. 1141.

[4] See Report of Committee D-9 on Electrical Insulating Materials, Appendix I, *Proceedings*, Am. Soc. Testing Mats., Vol. 40, p. 359 (1940).

Rate of Voltage Rise:

The rate of voltage rise specified for dielectric strength tests of insulating oil is 3 kv. per sec. This is faster than the rate of rise used in other A.S.T.M. test methods which is 1 kv. per sec.

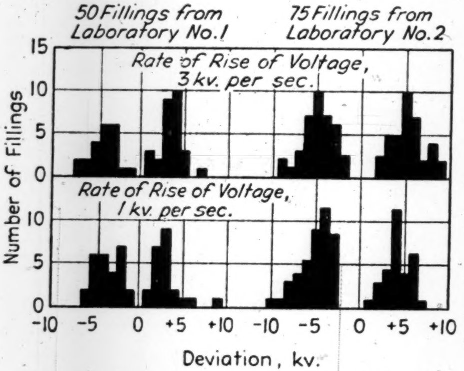


FIG. 2.—Frequency Distribution of Samples of Oil According to Maximum Deviation of Individual Breakdowns From the Average of Five Breakdowns on the Same Filling.

This problem was studied from two viewpoints, as follows:

(*a*) Will a lower rate of rise reduce the deviation between individual breakdowns?

(*b*) Are the standard indicating voltmeters able accurately to follow the voltage at a 3 kv. per sec. rate of rise?

Detailed data from two laboratories submitted to date do not show any marked improvement when using 1 kv. per sec. over the standard rate of 3 kv. per sec. The results on 50 samples tested by one laboratory and 25 samples tested by the other laboratory are plotted in Fig. 2 and show about the same deviation pattern. Two other laboratories reported results but not in sufficient detail for analysis as above. A summary of the results from the four laboratories is given in the following table:

Laboratory	Number of Samples	Average Breakdown, kv.		Average of 1 kv. per sec. Fillings Below Average of 3 kv. per sec. Fillings, kv.	Number of Samples Showing a Higher Value at	
		3 kv. per sec.	1 kv. per sec.		3 kv. per sec.	1 kv. per sec.
Consolidated Edison......	50	27.3	25.1	2.2	37	8
Commonwealth Edison......	25	34.7	32.7	2.0	21	
General Electric.....	35	37.8	36.1	1.7	27	2
Boston Edison......	32	30.5	30.2	0.3		

The results from all four laboratories do not show that there is a marked lowering of dielectric strength although the trend is slightly downward for the lower rate. If the lower rate were adopted present standards would probably be lowered.

The study of rate of voltage rise has not been completed and at present no conclusions reached.

Instrument Accuracy:

In connection with the rate of voltage rise a serious condition exists in the selection of a suitable instrument. Data were taken by having indicating voltmeters of different manufacture connected to a source of potential which could be varied at a rate equivalent to 3 kv. per sec. and 1 kv. per sec. on the testing transformer. The control was motor driven therefore insuring a uniform rate of rise. Readings were taken at division points equivalent to different high-voltage breakdown values. The results are shown on Fig. 3. This chart shows that the more accurate and expensive instruments due to better damping, are not sufficiently accurate at the 3-kv. per sec. rate. This data does indicate the necessity for checking the performance of the instrument used with the present rate of 3 kv. per sec. and may be the factor influencing the decision to use the lower rate of rise.

Momentary Discharges:

The study of momentary discharges was undertaken in three laboratories. Momentary discharges are defined as arcs in the insulating fluids, noted audibly or visibly during dielectric strength tests, which do not cause a permanent arc between the electrodes and are not effective in either causing the circuit breaker to open or returning the needle of the indicating instrument to zero. It was found during the investigation that a characteristic crackling sound always accompanies the momentary discharge.

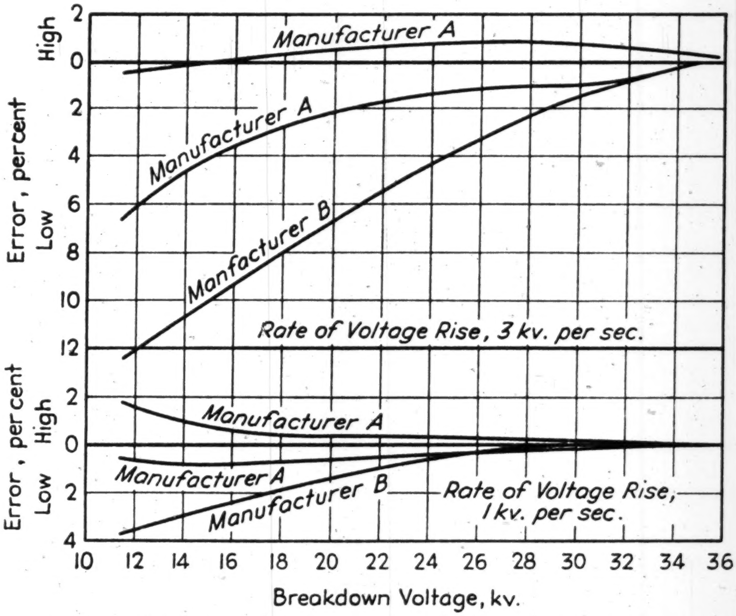


FIG. 3.—Voltmeter Indications at Various Rates of Voltage Rise.

One laboratory reported the results obtained on 3195 cup fillings during routine testing. Except for keeping of records on momentary discharges, no change was made in A.S.T.M. Methods D 117. For the purpose of this investigation, however, each cup filling tested was classified as satisfactory when the average of five consecutive breakdowns was 26.0 kv. or over, and as unsatisfactory when the average was below 26.0 kv. The insulating fluids were grouped as new oil, reconditioned oil, used oil (tested before reconditioning), and askarel.

A summary of the number of cup fillings tested, as given in Table II, shows that momentary discharges were observed on less than 2 per cent of the total.

The average dielectric strength of the cup fillings, the average kilovolts at which the momentary discharge occurred, and the average kilovolts at which the permanent breakdown took place after the momentary discharge are shown in Table III. A sensitive relay rated at 10 ma. was used in the high voltage circuit of one of the test sets used in this investigation. Although the momentary discharges occurred between 6 and 21 kv. (average, 11 kv.), the relay did not trip the circuit breaker on any of these discharges. On permanent breakdowns falling within this range of voltage, the relay would operate to open the circuit within 0.01 sec. This tends to indicate that a momentary and a permanent discharge are two different phenomena.

TABLE II.—SUMMARY OF MOMENTARY DISCHARGES OBSERVED ON INSULATING FLUIDS.

Insulating Fluid	Number of Cup Fillings Tested in Dielectric Strength								
	Total Cup Fillings Tested	Tested Satisfactory[a]				Tested Unsatisfactory[b]			
		Fillings with No Momentary Discharges	Percentage of Total	Fillings With Momentary Discharges	Percentage of Total	Fillings with No Momentary Discharges	Percentage of Total	Fillings With Momentary Discharges	Percentage of Total
New oil	1534	1088	70.9	0	0.0	434	28.3	12	0.8
Reconditioned oil	670	417	62.3	1	0.1	241	36.0	11	1.6
Used oil	509	248	48.7	0	0.0	240	47.2	21	4.1
Askarel	482	348	72.2	2	0.4	119	24.7	13	2.7
Total, all fluids	3195	2101	65.7	3	0.1	1034	32.4	57	1.8

[a] Cup fillings classified as satisfactory when average of five breakdowns is 26.0 kv. or over.

[b] Cup fillings classified as unsatisfactory when average of five breakdowns is less than 26.0 kv.

TABLE III.—DIELECTRIC STRENGTH AVERAGES[a] ON INSULATING FLUIDS ON WHICH MOMENTARY DISCHARGES WERE NOTED.

Insulating Fluid	Number of Samples	Number of Cup Fillings	Average Dielectric Strength of Cup Fillings, kv.	Number of Momentary Discharges	Kilovolts at Which Momentary Discharges Occurred, kv.			Averaged Dielectric Strength of Tests on Which Momentary Discharges Occurred, kv.
					Max.	Min.	Avg.	
New Oil:								
Satisfactory	0	0	...	...	...	...	...	...
Unsatisfactory	11	12	22.0	14	21.0	7.0	13.0	18.5
Reconditioned Oil:								
Satisfactory	1	1	26.0	1	14.0	14.0	14.0	15.5
Unsatisfactory	10	11	20.0	13	21.0	8.0	13.5	17.5
Used Oil:								
Satisfactory	0	0	...	...	...	...	...	...
Unsatisfactory	13	21	16.0	48	13.5	6.0	10.5	14.5
Askarel:								
Satisfactory	2	2	30.0	2	11.0	10.5	11.0	23.5
Unsatisfactory	13	13	17.0	17	11.0	8.0	9.0	14.5
Total	50	60		95				

[a] Five dielectric breakdown tests made on each cup filling.

The frequency distribution of momentary discharges according to the number of discharges per cup filling and the successive test on which they occurred are shown in Table IV. The results show that on unsatisfactory used oil a majority of the cup fillings had more than one momentary discharge. However, on the other types of insulating fluid usually only one momentary discharge occurred per cup filling. The table also shows that the majority of momentary discharges do not cocur on the first test.

In a second laboratory 448 cups were tested and the momentary discharges recorded. A summary of the data follows:

Total number of cups tested	448
Number of cups showing momentary discharge	30
Number of momentary discharges in 30 cups	42
Number of deviations of momentary discharge from cup average below 25 per cent	12
Number of deviations of momentary discharge from cup average above 25 per cent	30
Number of deviations of breakdown following momentary discharge from cup average above 25 per cent	7
Number of deviations of breakdown following momentary discharge from cup average below 25 per cent	23

These tests showed that in 23 cases a retest would have been required by the dielectric strength test in A.S.T.M. Method D 117 if momentary discharges were taken into account, where no retest is now required.

TABLE IV.—FREQUENCY DISTRIBUTION OF MOMENTARY DISCHARGES ON SUCCESSIVE BREAKDOWN TESTS[a] ON INSULATING FLUIDS.

Insulating Fluid	Number of Cup Fillings Showing Momentary Discharges	Number of Cup Fillings Classified According to Number of Momentary Discharges per Filling					Total Momentary Discharges	Number of Momentary Discharges Classified According to the Breakdown Test on Which They Occurred				
		Discharges per Filling										
		1	2	3	4	5		First Test	Second Test	Third Test	Fourth Test	Fifth Test
New Oil:												
Satisfactory	0	0	0	0	0	0	0	0	0	0	0	0
Unsatisfactory	12	10	2	0	0	0	14	2	8	3	1	0
Total	12	10	2	0	0	0	14	2	8	3	1	0
Reconditioned Oil:												
Satisfactory	1	1	0	0	0	0	1	1	0	0	0	0
Unsatisfactory	11	9	2	0	0	0	13	4	3	4	2	0
Total	12	10	2	0	0	0	14	5	3	4	2	0
Used Oil:												
Satisfactory	0	0	0	0	0	0	0	0	0	0	0	0
Unsatisfactory	21	8	6	2	3	2	48	20	11	9	5	3
Total	21	8	6	2	3	2	48	20	11	9	5	3
Askarel:												
Satisfactory	2	2	0	0	0	0	2	1	0	1	0	0
Unsatisfactory	13	10	2	1	0	0	17	5	2	6	3	1
Total	15	12	2	1	0	0	19	6	2	7	3	1
Grand Total	60	40	12	3	3	2	95	33	24	23	11	4

[a] Five successive breakdown tests made on each cup filling.

The third laboratory reported results of tests on 100 samples, of which 98 samples were from apparatus in service. All tests were made following the standard procedure. Only one momentary discharge was noted at 14 kv., whereas the breakdown occurred at 32 kv.

For the present the committee has continued the previous procedure of neglecting momentary discharges but will continue to study further data.

Effect of Electrode Shape:

Two laboratories have made tests with various shape electrodes. One laboratory made a few comparative tests with the standard flat electrodes and experimental spherical electrodes. The experimental test cup consisted of a sphere and hemisphere constructed to obtain a uniform gap spacing without stress concentration. The experimental test cup required a much smaller sample than the standard test cup and from the few samples tested seemed to show greater sensitivity to the presence of water.

The other laboratory submitted data on 191 samples showing a comparison between square-edged electrodes and round-edged electrodes. A study of the results showed that the average dielectric strength of the fillings tested with the round-edged electrodes were 1.7 kv. higher than the fillings tested with the square-edged electrodes. It was also noted that this difference increased considerably for the samples that tested above 30 kv. The frequency distribution of the maximum percentage deviation of the individual breakdown from the average of five breakdowns on each filling is given in Fig. 4 and shows that the deviations are greater with the round-edged electrodes.

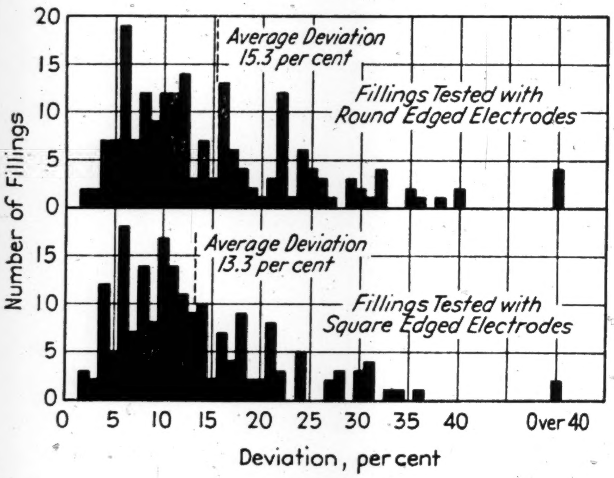


FIG. 4.—Frequency Distribution of 191 Samples of Oil According to Maximum Percentage Deviation of Individual Breakdowns from the Average of Five Breakdowns on the Same Filling.

NOTE.—Two fillings tested from each sample; one in cup with square-edged electrodes and the other in cup with round edged electrodes.

This investigation is being continued.

Effect of Shaking the Sample:

In A.S.T.M. Methods D 117 – 43, the current dielectric strength test[5] contains the following provision in Section 23 (*e*) which was originally approved in 1926:

> The sample in the container shall be shaken so as to thoroughly mix the oil before filling the test cup. This is even more important with used than with new oil as the impurities may settle to the bottom and the test may be misleading

A study of the procedures followed by different laboratories as shown in Table I indicated that this section has received various interpretations and should be clarified.

If a sample is shaken sufficiently to thoroughly mix the liquid the 3-min. waiting period between filling the test cup and applying the voltage is not sufficient to allow the air bubbles to escape. Two laboratories have submitted results of tests made to determine the rate of air escape from an air-liquid emulsion and the recovery of dielectric strength after vigorous shaking.

One laboratory tested three liquids of different viscosity and stated that if the liquid is shaken before the dielectric test, the period of time necessary to eliminate the air from the liquid is a function of the liquid tested and depends to a large extent on the liquid viscosity at the temperature of test. For tests at 25 C. the liquids must be allowed to stand for at least as long as indicated in the following table:

---

[5] A "tentative revision" of the dielectric strength test procedure has been accepted by the Society and is published in the 1943 Supplement to Book of A.S.T.M. Standards, Part III, p. 531.

Transformer oil (Saybolt Universal viscosity of 58 sec. at 37.8 C.)	15 min.
Light cable oil (Saybolt Universal viscosity of 100 sec. at 37.8 C.)	45 min.
Askarel (Saybolt Universal viscosity of 54 sec. at 37.8 C.)	20 min.

Tests were also made to determine the length of the rest period necessary for the liquid to reach a stable dielectric strength value. These tests were made with oils of various water content and are as follows:

Water Content, ppm.	Time to Reach Stable Dielectric Value (25 C.), min		
	Transformer Oil	Light Cable Oil	Askarel
3 to 7	20	33+	30
17 to 35	20	33+	30
59 to 67	12	10	20

The second laboratory made tests on three similar liquids each with three different water contents. The results of these tests showed that vigorous shaking was necessary in order to get reproducible results on those samples which contained free water as contrasted with dissolved water. When the water is in solution the same results are obtained whether the sample is shaken or just inverted. If samples containing free water are allowed to stand for more than 15 min. after shaking there is a definite tendency for some of the cup fillings to show satisfactory dielectric strength and therefore misleading results.

Duration of Arc Current:

Results of tests made on insulating oils showed that there was no systematic decrease in the breakdown of successive tests on the same filling, either when the test set was equipped with a high-speed-circuit opening device or when the circuit was opened by hand. However, tests on askarels showed a systematic decrease and the average breakdown of the fifth test of 80 fillings was 9 kv. below the average breakdown of the first test when the circuit was opened by an ordinary circuit-breaker. After installing a high-speed circuit breaker as many as 15 breakdowns were made on the same filling with no decrease in the dielectric strength. Data on 40 samples of askarel tested with the high-speed-circuit opening device showed the average breakdown of the fifth test to be slightly higher than the average breakdown of the first test.

The section is continuing work on those items which have not been concluded. From the projects which were finished it was possible to make revisions in the standard. These revisions have been approved as tentative and others will be made later.

Acknowledgment:

This report is submitted to record the valuable data which have been contributed through the cooperation of a number of laboratories. Acknowledgment is made to the members of the section and the participating laboratories for the success to date.

Respectfully submitted on behalf of Section L on Dielectric Strength,

O. E. FAWCETT,
Chairman.

APPENDIX III

PROPOSED METHODS OF TEST FOR GAS CONTENT OF INSULATING OIL[1]

These are proposed methods and are published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 260 S. Broad St., Philadelphia 2, Pa.

Scope

1. These methods of test are intended for determining the gas content of electrical insulating oils of low viscosities of the general order of 100 sec. Saybolt Universal at 100 F., such as are used in capacitors and paper insulated lead-covered electric cables of the oil-filled type. The determination of gas content is desirable for any insulating oil of these properties intended for use in a degassed state. Two methods are covered: a routine method, and a referee method for use when a test of high accuracy is desired (see Explanatory Note).

ROUTINE METHOD

Nature of Test

2. The routine method consists essentially of feeding the oil into an evacuated chamber in such a manner that the oil is thoroughly exposed to the vacuum, allowing free escape of any dissolved gas. From the volume of oil admitted to the chamber, the temperature, the pressure produced, and volume occupied by the released gas, the gas volume under standard conditions of pressure and temperature may be calculated as a percentage by volume of oil.

Sampling

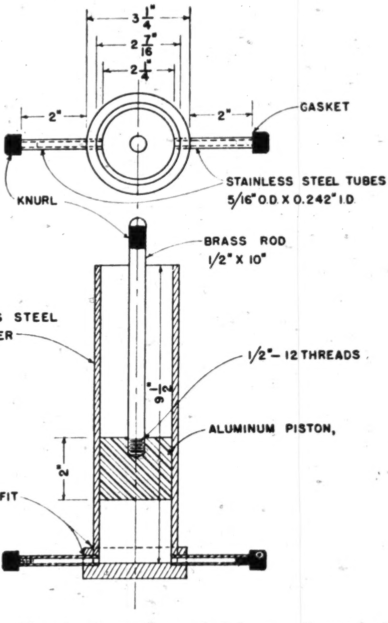
3. (*a*) When convenient, the degassing chamber of the measuring equipment shall be connected directly to the container from which the oil is to be sampled. This is usually not convenient and is often impossible. The method of sampling described in Paragraph (*b*) is recommended as an alternate (Note).

NOTE.—This sampling method has been in use by two laboratories for many years.

(*b*) The sample container shown in Fig. 1 shall consist of a stainless steel cylinder $2\frac{1}{4}$ in. in inside diameter and $9\frac{1}{2}$ in. in length, closed at the bottom. An aluminum piston shall be inserted in the bore of the cylinder accurately machined for an easy sliding fit. Two nipples, diametrically opposed, shall be inserted at the extreme bottom of the cylinder. Each nipple shall have a screw plug at the end with a gasket for sealing. All connections to the measuring equipment from the sample container should be of glass or metal tubing. Butted joints connected by short sections of heavy-walled rubber tubing may be used provided the tubing is thoroughly coated with suitable sealing compound. All samples shall be taken under slight oil pressure, with the following sequence of operations: Push the piston to the extreme bottom of the cylinder. Remove plugs from both nipples. Hold the cylinder so that the nipples point in a vertical direction. By means of a rubber tube connection, force oil in through the nipple in the lowest position and flush a few milliliters out the opposite nipple to remove any trapped air bubbles. Then insert the plug in the outlet nipple and allow oil to push the piston up to fill the cylinder. Hold the piston at the top of the cylinder with one hand and plug the inlet nipple. The aluminum piston "floats" on the oil as the level varies, due to temperature changes or removal of test samples and prevents contamination by absorption and diffusion. The piston shall be accurately fitted to move down freely with decreasing oil level to prevent voids forming under the piston which would allow rapid absorption of air by the top oil. When drawing the test sample continuously from the cylinder, it is advisable to weight the piston to insure maintenance of contact with the oil. Wide variations in the results are possible in two samples from the same source unless the greatest care is taken in the sampling procedure. This phase of the test is so involved with the details of what constitutes correct practice that ability to procure consistent representative samples depends, to a great extent, on wide experience. The chief precaution to insure procurement of representative samples involves a complete flushing of all piping and hose between the sample container and sample source, such as pothead, joint, cable, oil reservoir, etc., immediately preceding collection of the sample. All long pipe lines should be eliminated where possible. After taking the sample, it is very important to see

---

[1] These proposed methods are under the jurisdiction of the A.S.T.M. Committee D-9 on Electrical Insulating Materials. Published as information, June, 1944.


3 1/4"
2 7/16"
2 1/4"
2"
2"
GASKET
KNURL
STAINLESS STEEL TUBES 5/16" O.D. X 0.242" I.D.
BRASS ROD 1/2" X 10"
STAINLESS STEEL CYLINDER
1/2"– 12 THREADS
5/8"
ALUMINUM PISTON,
2"
PRESS FIT

NOTE.—The aluminum piston shall have a diametrical clearance of 0.0005 to 0.0010 in.

FIG. 1.—Apparatus for Sampling Oils for Determination of Gas Content.

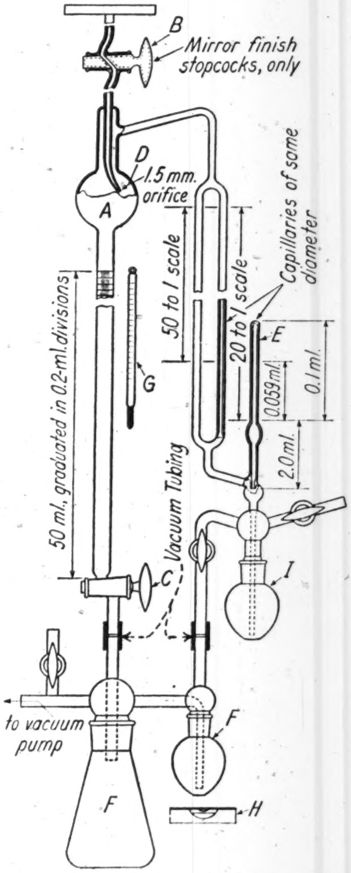

B
Mirror finish stopcocks, only
D
1.5 mm. orifice
A
50 to 1 scale
20 to 1 scale
Capillaries of same diameter
E
0.1 ml.
0.059 ml.
2.0 ml.
G
50 ml., graduated in 0.2-ml. divisions
Vacuum Tubing
C
I
to vacuum pump
F
F
H

FIG. 2.—Apparatus for Routine Determination of Gas Content of Insulating Oil.

that the piston always remains in contact with the oil prior to and during withdrawal of the test specimen.

Apparatus

4. The apparatus, shown in Fig. 2, shall consist of the following:

(*a*) *Degassing Chamber.*—Degassing chamber, *A*, made of heat-resistant glass[2] (with calibrated oil well at bottom), having fixed total space volume of about 175 ml. The oil well shall have a maximum capacity of 50 ml. and shall be calibrated in 0.2 ml. divisions.

(*b*) *Stopcocks.*—Glass stopcocks *B*, *C*, *J*, *K*, and *L*, which shall have large diameter barrels and a mirror finish to insure against leakage. Stopcock grease[3] shall be used on all stopcocks and ground-glass joints.

(*c*) *Pipette.*—Glass pipette or "atomizer", *D*, placed to drop oil on side of degassing chamber.

(*d*) *Pressure Gage.*—Pressure gage, *E*, of modified McLeod type marked for two scale factors, 50 to 1 and 20 to 1. This will provide ranges sufficient for most testing. If a higher pressure range is desired, a separate complete equipment using an absolute mercury manometer in place of the McLeod gage may be used.

(*e*) *Oil Traps.*—Two oil traps, F_1 and F_2.

(*f*) *Thermometer*, *G*.

(*g*) *Level.*—Spirit level, *H*, normal to vertical axes of mercury columns.

(*h*) *Mercury Well*, *I*.

Calibration of Apparatus

5. Calibration and conditioning of the apparatus is often done by the manufacturer. If this has not been done, or if a check is desired, the following procedure may be used:

(*a*) Clean the glass assembly with a cleaning solution, wash with distilled water, and dry. Weigh the empty tester with slight film of grease on the stopcocks. Record weight in grams as *W*. Fill with distilled water and weigh. Record weight in grams as *T*. The difference between *W* and *T* is the volume of the tester in milliliters. Correction for temperature of water may be made, but is an unnecessary refinement.

(*b*) Empty and thoroughly dry equipment in oven. Pour the mercury for the McLeod gage into the mercury well, grease the stopcocks and ground-glass joints and assemble the apparatus. Attach to the mounting board (with spirit level horizontal) and align with a plumb bob and line.

Procedure

6. (*a*) Sample and apparatus should be at room temperature (20 to 30 C.).

(*b*) Evacuate the degassing chamber with stopcock *B* closed and stopcock *C* open.

NOTE.—These stopcocks must be accurately ground and kept well greased to prevent leaks.

(*c*) When the McLeod gage reading is reasonably constant and less than 0.1 mm. (absolute pressure) close stopcock *C* for about 15 min. to test for any leaks. No observable pressure change should occur in this time. (Let vacuum pump run continuously to enhance seal of stopcock *C*.)

(*d*) Flush oil slowly from sample through stopcocks *B* and *C* so as to thoroughly wash walls of glass tubing and to remove any trapped air bubbles in system above stopcock *B*. (About 50 ml. of oil are commonly used for this flushing.)

(*e*) Reevacuate the degassing chamber, close stopcock *C* and by careful manipulation of stopcock *B* feed oil from the sample container into the degassing chamber at a very slow rate so that the oil falls in single drops from pipette *D*. This rate will generally average 1 drop per second or less. The oil should show no appreciable tendency to bubble or foam after falling into the oil well at the bottom of the degassing chamber. If this occurs the rate of flow should be decreased.

---

[2] Pyrex glass is satisfactory for this purpose.

[3] A stopcock grease equivalent to No. 15521A Vacuum Sealing Compound, Central Scientific Co., Chicago, Ill., has been found satisfactory for this purpose.

(*f*) When 25 ml. of oil have been degassed, close stopcock *B* and read the McLeod gage and thermometer. In reading the gage the mercury level shall be adjusted by manipulation of stopcocks *J* and *K*.

(*g*) Empty the oil reservoir into the oil trap, and complete the evacuation of the degassing chamber for the next test.

Calculation

7. The gas content shall be calculated as follows:

$$G = \frac{35.9\,[(V - V_1)\,P_2 - VP_1]}{(273 + t)\,V_1}$$

where:

G = gas content (at 760 mm. of mercury and 0 C.) expressed as a percentage by volume of oil,
V = known total fixed volume of apparatus in milliliters,
V_1 = volume of oil in milliliters,
P_1 = initial pressure of gas in chamber, in millimeters of mercury,
P_2 = final pressure of gas in chamber, in millimeters of mercury,
t = temperature of chamber, in degrees Centigrade. (The room temperature shall be read from thermometer, *G*.)

REFEREE METHOD

Nature of Test

8. The referee method consists essentially of feeding the oil into an evacuated chamber in such a manner that the oil is thoroughly exposed to the vacuum, allowing free escape of any dissolved gas. From the volume of oil admitted to the chamber, the temperature, the pressure produced, and the volume occupied by the released gas, the gas volume under standard conditions of pressure and temperature may be calculated as a percentage by volume of oil.

Sampling

9. The oil shall be sampled as described in Section 3.

Apparatus

10. The apparatus, shown in Fig. 3, shall consist of the following:

(*a*) *Degassing Chamber.*—Degassing chamber, *A*, made of heat-resistant glass[2] (with calibrated oil well at bottom), having fixed total space volume of about 175 ml. The oil well shall have a maximum capacity of 50 ml. and shall be calibrated in 0.2-ml. divisions.

(*b*) *Stopcocks.*—Glass stopcocks, *B*, *C*, *L*, *M*, *N*, which shall have large diameter barrels and a mirror finish to insure against leakage. Stopcock grease[3] shall be used on all stopcocks and ground-glass joints.

(*c*) *Pipette.*—Glass pipette or "atomizer," *D*, placed to drop oil on side of degassing chamber.

(*d*) *Pressure Gage.*—Pressure gage, *E*, of modified McLeod type marked fot two scale factors, 50 to 1 and 20 to 1. This will provide ranges sufficient for most testing. If a higher pressure range is desired, a separate complete equipment using an absolute mercury manometer in place of the McLeod gage may be used for the high pressures.

(*e*) *Oil Traps.*—Two oil traps, F_1 and F_2.

(*f*) *Thermometer*, *T*.

(*g*) *Level.*—Spirit level, *H*, normal to the vertical axes of mercury columns.

(*h*) *Mercury Well*, *I*.

(*i*) *Cold Trap*, *J*.

(*j*) *Oven.*—An oven, *K*, enclosing the degassing chamber, *A*, provided with suitable means for reading, maintaining, and regulating temperature in a range from 30 to 150 C. Temperature shall be measured by means of a thermocouple fastened to the oil chamber at the 25-ml. mark and suitably shielded to eliminate radiation errors.

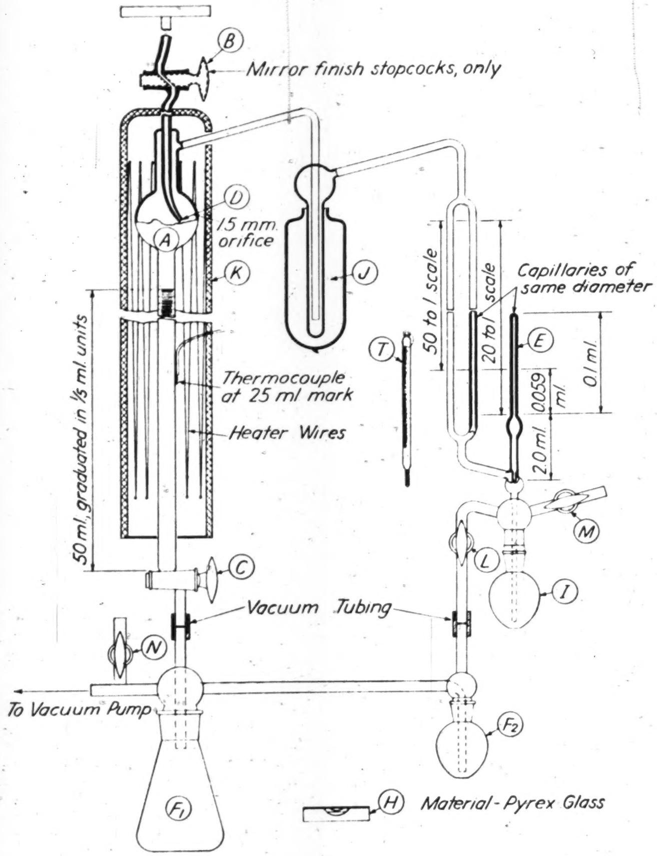

B
Mirror finish stopcocks, only
D
1.5 mm. orifice
A
K
J
50 to 1 scale
20 to 1 scale
Capillaries of same diameter
E
T
0.1 ml.
.0059 ml.
2.0 ml.
Thermocouple at 25 ml mark
Heater Wires
50 ml, graduated in 1/5 ml units
M
L
I
C
Vacuum Tubing
N
To Vacuum Pump
F2
F1
H
Material-Pyrex Glass

FIG. 3.—Apparatus for Referee Determination of Gas Content of Insulating Oil.

Calibration of Apparatus

11. Calibration and conditioning of the apparatus is often done by the manufacturer. If this has not been done, or if a check is desired, the following procedure may be used:

(*a*) Clean the glass assembly with a cleaning solution, wash with distilled water, and dry. Weigh the empty tester, with a slight film of grease on the stopcocks, and record the weight in grams as *W*. Fill with distilled water, weigh, and record the weight in grams as *T*. The difference between *W* and *T* is the volume of the tester in milliliters. Correction for temperature of water may be made, but is an unnecessary refinement.

(*b*) Empty and thoroughly dry the equipment in an oven. Pour the mercury for the McLeod gage into the mercury well, grease the stopcocks and groundglass joints and assemble the apparatus. Attach to the mounting board (with spirit level horizontal) and align with a plumb bob and line.

(*c*) Calculate as closely as possible the separate volumes of the degassing chamber, V_d, enclosed in the oven, and the section of the cold trap, V_t, enclosed in the vacuum flask.

Procedure

12. (*a*) Regulate the temperature of the oven to 50 C. and make certain that it remains constant within plus or minus 2 C. for at least 30 min.

(*b*) Fill the vacuum flask surrounding the cold trap, *J*, with either liquid air or carbon dioxide snow, or equivalent.

(*c*) The sample and apparatus shall be at room temperature (20 to 30 C.) with the exception of the parts mentioned under Paragraphs (*a*) and (*b*).

(*d*) Evacuate the degassing chamber with stopcock *B* closed and stopcock *C* open.

NOTE.—These stopcocks must be accurately ground and kept well greased to prevent leaks.

(*e*) When the McLeod gage reading is reasonably constant and less than 0.1 mm. (absolute pressure), close stopcock *C* for about 15 min. to test for any leaks. No observable pressure change should occur in this time. (Let vacuum pump run continuously to enhance seal of stopcock *C*).

(*f*) Flush oil slowly from the sample through stopcocks *B* and *C* so as to wash thoroughly the walls of the glass tubing and to remove any trapped air bubbles in system above stopcock *B*. (About 50 ml. of oil are commonly used for this flushing).

(*g*) Reevacuate the degassing chamber, close stopcock *C*, and by careful manipulation of stopcock *B* feed oil from the sample container into the degassing chamber at a very slow rate so that the oil falls in single drops from pipette *D*. This rate will generally average one drop per second or less. The oil should show no appreciable tendency to bubble or foam after falling into the oil well at the bottom of the degassing chamber. If this occurs, the rate of flow should be decreased.

(*h*) When 25 ml. of oil have been degassed, close stopcock *B* and read the McLeod gage, the temperature of the room and of the degassing chamber. The temperature of the cold trap t_t will be known and will depend, of course, upon the coolant used. (Temperature of liquid air is −194 C., and of carbon dioxide snow −78 C.). In reading the McLeod gage the mercury level shall be adjusted by manipulation of stopcocks *L* and *M*.

(*i*) Empty the oil reservoir into the oil trap, and complete the evacuation of the degassing chamber for the next test.

Calculation

13. The gas content shall be calculated as follows:

$$G = \frac{35.9}{V_1}\left[\frac{(V - V_d - V_t)(P_2 - P_1)}{273 + t_a} + \frac{(V_d - V_1)P_2 - V_dP_1}{273 + t_d} + \frac{V_t(P_2 - P_1)}{273 + t_t}\right]$$

where:

G = gas content (at 760 mm. of mercury and O C.) expressed as a percentage by volume of oil,

V = known total fixed volume of apparatus in milliliters,

V_1 = volume of oil in milliliters,

V_d = volume of degassing chamber in milliliters,

V_t = volume of cold trap in milliliters,

P_1 = initial pressure of gas in chamber in millimeters of mercury,

P_2 = final pressure of gas in chamber in millimeters of mercury,

t_a = ambient temperature in degrees Centigrade read on thermometer, *T*.

t_d = temperature of degassing chamber *A* in degrees Centigrade, and

t_t = temperature of cold trap in degrees Centigrade.

NOTE.—The calculation may appear to be tedious, but when the fixed volumes and temperatures are substituted in the formula, it will be found that it can be simplified considerably. Simplification will also be aided if P_1 can be made low enough to be negligible.

EXPLANATORY NOTE

NOTE.—There are several possible sources of error in the routine method but due to the convenience in making the test by this procedure, and the simplicity and portability of the test equipment this method is considered satisfactory for routine tests. The possible errors due to accuracy of readings are relatively small for normal ranges of gas content.

Consider the case of an oil with 0.10 per cent gas. For normal procedure, values of initial pressure and end point would be 0.100 and 0.255 mm. of mercury, respectively. This pressure increase would be developed by 25 ml. of oil tested at 25 C. (in a degassing chamber of total fixed space volume of approximately 175 ml.).

Pressures can be read to plus or minus 0.004 mm. of mercury. (This is equivalent to reading the mercury columns of the gage to plus or minus 0.20 mm. assuming a 50 to 1 scale factor of the gage). Oil volume can be read to plus or minus 0.05 ml.

Assuming errors in pressure and volume readings adding to give maximum deviation, the resultant error would be plus or minus 0.0067 in 0.10 per cent, equivalent to a percentage error of 6.7 per cent for gas contents of this low order.

The above analysis also applies to the referee method. The only difference would be due to the different temperatures used and the correction would be negligible.

Attention, however, is called to the following possible errors present in this apparatus: It is well known that the McLeod gage gives correct pressure readings only for pure gases. If vapor is present, the gage will give entirely erroneous readings, due to the high-pressure ratios present between the two columns of mercury, and consequent condensation of vapor in the high-pressure side. This would cause the pressure reading to be low with a resultant low gas content determination.

In the referee method this possibility of error is eliminated by the use of a cold trap to freeze out any such vapors which may be removed from the oil. This also allows the use of a higher temperature in the degassing chamber, thereby lowering the viscosity of the oil under test and increasing the ease of removal of gas.

Attention should also be called to the possibility of gas leakage through any rubber tubing which may be present in the sample supply line. This may occur in spite of positive oil pressure being maintained in this line, causing, of course, higher gas content of the sample.

Also, unless sampling is done with extreme care by an experienced operator, an increase in the gas content of the sample may very easily occur, causing a high reading of gas content. Tests have also shown that all of the gas may not be entirely removed from the oil at room temperature. This error may amount to as much as 50 per cent, and, of course, results in low readings of gas content.

REPORT OF SECTIONAL COMMITTEE C59

ON

ELECTRICAL INSULATING MATERIALS

Sectional Committee C59 on Electrical Insulating Materials held one meeting during the year: in Philadelphia, Pa., on February 21, 1944.

At the February meeting, the present officers of the committee were re-elected for the ensuing term of two years.

The following standards, submitted to the American Standards Association on the recommendation of Sectional Committee C59, were approved as American Standard during the year:

A.S.T.M. Standard Methods of:

Testing Molded Materials Used for Electrical Insulation (A.S.T.M. D 48 - 43 T; ASA C59.1—1944),
Testing Electrical Insulating Oils (D 117 - 43; C59.2—1944),
Test for Impact Resistance of Plastics and Electrical Insulating Materials (D 256 - 43 T; C59.11—1944),
Testing Sheet and Plate Materials Used in Electrical Insulation (D 229 - 43; C59.13—1943),
Testing Laminated Tubes Used in Electrical Insulation (D 348 - 42; C59.14—1943),
Testing Laminated Round Rods Used in Electrical Insulation (D 349 - 42; C59.15—1943),
Testing Shellac Used for Electrical Insulation (D 411 - 42; C59.18—1944),

NEMA Standards:

Laminated Phenolic Products - Standards (NEMA 39 - 57; ASA C59.16—1944), and
Recommended Practice for Machining and Punching of Laminated Phenolic Plate (NEMA 39 - 58; C59.17—1944).

In accordance with action taken at the February meeting, a ballot is now being conducted in the sectional committee on the proposed submittal of the A.S.T.M. Tentative Method of Test for Oil Content of Paraffin Wax (D 721 - 43 T) to the ASA for approval as American Standard in view of the extensive use of paraffin wax as electrical insulating material. This question is also under consideration in Sectional Committee Z11 on Petroleum Products and Lubricants.

The sectional committee received advice during the year that the War Committee on Radio—formed under the war standards procedure of the ASA at the request of the War Production Board to set up war standards for components for military radio to help speed production of radio equipment for the Army and Navy, make replacements of parts easier, and conserve materials—is to be terminated, the work to be taken over by a joint Army-Navy group. At the time this project was initiated, the Armed Forces could not spare the personnel required to handle such a program. Since then, conditions have changed and the Army-Navy Electronics Standards Agency (ANESA) was established recently to take over this work. Fourteen standards developed by the War Committee on Radio had already been approved, of which the following are of interest to Sectional Committee C59:

Ceramic Radio Insulating Materials, Class L - C75.1—1943,
Steatite Radio Insulators - C75.2—1943,
Ceramic Radio Dielectric Materials, Class H - C75.4—1943,

Glass-Bonded Mica Radio Insulators – C75.6—1943,
Glass Radio Insulators – C75.8–1943, and
Porcelain Radio Insulators – C75.14—1944.

To avoid any substantial loss of effort already expended, those subjects which are nearly completed will be concluded under the war procedure of the ASA, and the remaining specifications will be handled exclusively by ANESA. In completing the work, ANESA will utilize the current ASA drafts of the specifications which they have started to develop. The existing ASA task groups which have been developing the standards will be disbanded, as ANESA will seek the cooperation of industry by other means.

Respectfully submitted on behalf of the sectional committee,

H. L. CURTIS,
Chairman.

R. E. HESS,
Secretary.

REPORT OF COMMITTEE D-11
ON
RUBBER PRODUCTS

Committee D-11 on Rubber Products held one meeting during the year, in Cincinnati, Ohio, on March 3, 1944, in connection with the spring group meetings of A.S.T.M. committees. On March 2, 1944, the committee sponsored the technical program for the 1944 Spring Meeting of the Society in Cincinnati, consisting of an important symposium on "The Applications of Synthetic Rubbers."[1] The thirteen papers, presented in two sessions, were of great value in providing technical information concerning the development of synthetic rubber, and their properties and applicability to products formerly made from natural rubber. This symposium was especially timely in view of the large scale conversion from natural rubber to synthetic necessitated by the war conditions.

At the March meeting, the committee accepted with regret the resignation of its chairman, J. H. Ingmanson, who was obliged to relinquish his office as chairman because of added duties and responsibilities incident to his becoming Vice-President of the Whitney-Blake Co., an important producer of insulated wire and cable. The committee has since been acting under the leadership of its Vice-chairman, Simon Collier, who was unanimously chosen Acting Chairman.

Subsequent to the 1943 Annual Meeting, Committee D-11 presented to the Society through Committee E-10 on Standards the following recommendations:

New Tentative Methods of:

Calibrating a Light Source Used for Accelerating the Deterioration of Rubber (D 749 - 43 T), and
Test for Resistance to Accelerated Light Aging of Rubber Compounds (D 750 - 43 T).

Revision of Tentative Methods of:

Chemical Analysis of Rubber Products (D 297 - 43 T),
Test for Changes in Properties of Rubber and Rubber-Like Materials in Liquids (D 471 - 43 T),
Testing Asphalt Composition Battery Containers (D 639 - 43 T), and
Testing Compressed Asbestos Sheet Packing (D 733 - 43 T).

Methods D 749 and D 750 were published as proposed methods in 1940 and have since found use in a number of laboratories and in some specifications. In presenting them for publication as tentative, the committee made extensive revisions based on the experienced gained. The revision in Methods D 297 consists of the addition of the procedure for the direct determination of rubber hydrocarbon by the chromic acid oxidation method described by Burger, Donaldson, and Baty.[2] The revision in Method D 471 covers the addition of three standard oils for use when testing the action of petroleum base lubricating oils on rubber. In Methods D 639, a number of details in the test procedures were altered and the procedures for determining manganese were corrected to make them more exact. Although Methods D 733 had been published only a few months, new work indicated that this material is affected by change in humidity and it became necessary to include a definite conditioning procedure prior to test. All of these recommendations were accepted[3] by Committee E-10 on November 20, 1943, and the new and revised tentative standards appear in the 1943 Supplement to Book of A.S.T.M. Standards, Part III.

---

[1] Symposium on Synthetic Rubbers, Am. Soc. Testing Mats. (1944). (Symposium issued as separate publication, March, 1944.)

[2] V. L. Burger, W. E. Donaldson, and J. A. Baty, "A Direct Determination of Rubber Hydrocarbon Chromic Acid Oxidation Method," ASTM BULLETIN, No. 120, January, 1943, p. 23.

On December 27, 1943, Committee E-10 accepted[3] the recommendation of Committee D-11 that the following specifications and methods of test be issued as tentative:

Tentative Specifications for:

Chloroprene Sheath Compound for Electrical Insulated Cords and Cables (D 752 – 43 T) [formerly issued as Emergency Standard ES – 28],
Chloroprene Sheath Compound for Electrical Insulated Cords and Cables Where Extreme Abrasion Resistance is Not Required (D 753 – 43 T) [formerly issued as Emergency Standard ES – 30],
Insulated Wire and Cable: Heat-Resisting Synthetic Rubber Compound (D 754 – 43 T), [formerly issued as Emergency Standard ES – 33],
Insulated Wire and Cable: Performance Synthetic Rubber Compound (D 755 – 43 T) [formerly issued as Emergency Standard ES – 34] and
New Tentative Methods of Testing Rubber-Coated Fabrics (D 751 – 43 T).

These new tentative standards appear in the 1943 Supplement to Book of A.S.T.M. Standards, Part III.

The Methods of Testing Rubber-Coated Fabrics represent the first result of the efforts of the committee to standardize testing in this field. It is expected that these methods will form a nucleus to which other procedures will be added when agreement is reached. The insulated wire specifications were originally published as emergency specifications, made necessary by the Limitation Order issued by the War Production Board that synthetic rubber be used in place of natural rubber. The two specifications for insulation compounds cover the use of GR-S rubber and the sheath compounds are made from GR-M (chloroprene) and had also previously been issued as emergency standards.

EMERGENCY ALTERNATE PROVISIONS AND EMERGENCY SPECIFICATIONS

No new emergency specifications were recommended during the year but revisions in the Emergency Specifications for Rubber Sheath Compound for Electrical Insulated Cords and Cables where extreme Abrasion Resistance is Not Required (ES – 6) were accepted by Committee E-10 on November 17, 1943. These specifications originally provided for the use of rubber in jacket compounds in conformity with War Production Board requirements but they did not cover the use of GR-S rubber. With the elimination of permission to use other rubber and the requirement that this material be made from GR-S, it became necessary to rewrite the emergency specifications. The revised specifications, entitled Emergency Specifications for GR-S Synthetic Rubber Sheath Compound for Electrical Insulated Cords and Cables, with a minor change in the requirement for minimum elongation at rupture became applicable to the permitted use as jackets. They have been issued under the designation ES - 6a and appear in the 1943 Supplement to Book of A.S.T.M. Standards, Part III.

---

[3] In submitting these recommendations to Committee E-10 on Standards, Committee D-11 reported the following results of the letter ballot vote from a committee membership of 123: *D 749*, affirmative 38, negative 0, ballots marked "not voting" 29; *D 750*, affirmative 42, negative 0, ballots marked "not voting" 25; *D 297*, affirmative 45, negative 0, ballots marked "not voting" 22; *D 471*, affirmative 48, negative 0, ballots marked "not voting" 19; *D 639*, affirmative 25, negative 1, ballots marked "not voting" 41; *D 733*, affirmative 34, negative 0, ballots marked "not voting" 33; *D 752* and *D 753*, affirmative 31, negative 1, ballots marked "not voting" 36; *D 754* and *D 755*, affirmative 32, negative 1, ballots marked "not voting" 35; *D 751*, affirmative 38, negative 1, ballots marked "not voting" 29.

Revisions were accepted on July 20, 1943, by Committee E-10 of the Emergency Alternate Provisions in the Standard Specifications for Friction Tape for General Use for Electrical Purposes (EA - D 69). This change removed the requirement limiting the amount of rubber hydrocarbon permitted in the tape. Also on November 27, 1943, Committee E-10 accepted a change in the Emergency Alternate Provisions in the Tentative Specifications for Insulated Wire and Cable: Ozone-Resistant Type Insulation (EA - D 574) whereby the insulation resistance constant was changed from 5280 to 1000. This change was necessary in order to permit the use of synthetic rubber under these specifications. Revised Emergency Provisions EA - D 69a and EA - D 574a have been issued in the form of stickers for attachment to the specifications to which they apply.

I. NEW TENTATIVE STANDARDS

Tentative Method of Test for Young's Modulus in Flexure of Natural and Synthetic Elastomers at Normal and Subnormal Temperatures.[4]—This method was developed by Subcommittee XXV on Low-Temperature Test for Rubber and Rubber-Like Materials for use in evaluating the low-temperature properties of vulcanized rubber and synthetic elastomers. Young's modulus in bending is determined at low temperatures and used as a measure of the cold-stiffening characteristics of the material. Provision is made in the method for measuring the stiffening effect produced either by crystallization or by second order transition (vitrification) whichever is involved in the material being tested. When the Tentative Method of Test for Low-Temperature Brittleness of Rubber and Rubber-Like Material (D 736 - 34 T) was developed last year the importance of low-temperature testing in connection with aircraft and cold-climate applications of rubber products was discussed. The inadequacy of the brittleness test was mentioned at that time and indication given that work would continue along these lines. The proposed method is recommended for publication as tentative as a continuance of this program and is intended to supplement rather than to replace the brittleness test Method D 736.

Tentative Specifications for Cellular Rubber Products.[5]—These specifications were developed by a special committee organized under the auspices of the Ordnance Department, U. S. Army, which included many of the members of Subcommittee XXII on Sponge Rubber Products. When the special committee had completed its work, the specifications were considered by the subcommittee looking toward their publication as an A.S.T.M. tentative standard in line with the work in progress in the subcommittee. It is now felt that the specifications are as satisfactory as can be prepared at this time. It is expected that they will be approved on a tentative basis by the Ordnance Department and in the interest of standardization they are recommended for publication as an A.S.T.M. tentative standard. It will be noted that these specifications follow the general form established by the Tentative Specifications for Rubber and Synthetic Rubber Compounds for Automotive and Aeronautical Applications (D 735 - 43 T).

II. REVISION OF TENTATIVE STANDARDS

The committee recommends that the following tentative standards be revised as indicated below and continued as tentative:

---

[4] This method was accepted as tentative by the Society and appears in the 1944 Book of A.S.T.M. Standards, Part III, p. 1802.

[5] These specifications were accepted as tentative by the Society and appear in the 1944 Book of A.S.T.M. Standards, Part III, p. 1886.

Tentative Methods of Testing Sponge Rubber Products (**D 552 - 43 T**).[6]—In connection with the large amount of work which has been done on specifications and methods of test for cellular rubber products during the past year, the committee finds that it is advisable to change the title of the present tentative methods by substituting the word "Cellular" for "Sponge" since this better describes the scope covered by the methods. Experience with these methods has indicated also that the procedure now given for measuring tensile strength and elongation should be omitted as these tests are of little value since these methods are not very satisfactory for evaluating this type of material. On the other hand, additional procedures covering low-temperature testing, measurement of water absorption, evaluation of compression-set characteristics, and measurement of the effect of oil have been added as these tests are of considerable importance in many of the applications of cellular rubbers. The revised tentative methods are appended hereto.[7]

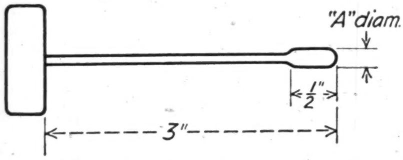
Tentative Methods of Testing Automotive Hydraulic Brake Hose (**D 571 - 40 T**).[8]—The following changes have been agreed upon by the Section on Hose of Technical Committee A and Subcommittee I on Mechanical Rubber Hose and are considered desirable improvements in the present tentative methods:

New Section 4.—Add a new Section 4 on measurements of hose, to read as follows, renumbering the subsequent sections accordingly:

> 4. *Measurements of Hose.*—(*a*) Constriction of the bore after assembly of the hose and fittings shall be measured with a gage plug as shown in the accompanying Fig. 1 with dimension "A" as prescribed in the detailed specifications for the hose. The gage plug shall weigh 2 ± 0.1 oz. The hose assembly shall be held in vertical position and the "A" diameter portion inserted into the end of the fitting. The gage shall be permitted to drop, of its own weight, a distance of 3 in. into the hose assembly. The time required to drop 3 in. shall not exceed 5 sec.
>
> (*b*) Length of hose assembly shall be measured with the assembly in a vertical position with a weight of 1.25 lb. ± 0.1 oz. attached to one end. A vernier caliper scale or equivalent shall be used and the length reported in inches and thousandths of an inch.

Section 4.—Renumber as Section 5 and add the following sentence: "The free length shall be the length between the fittings measured as described in Section 4 (*b*)."

Section 13.—Renumber as Section 14, omit the word "then" from the third sentence, and change the first two sentences from their present form: namely,



Gage plug shall weigh 2 ± 0.1 oz. Dimension "A" of the gage plug shall be as prescribed in the specifications for the hose.

FIG. 1.—Gage Plug for Testing Constriction of Bore of Hose.

> The adjustable header at the fixed end of the apparatus shall be so placed, with the addition of washers on the hose assembly where necessary, that the distance between the outside of the hexagon on the male end and the outside of the washer on the female end is $1\frac{3}{4}$ in. ± $\frac{1}{64}$ in. less than the straight length of each individual assembly. This approximate distance for each assembly shall be measured on a straight perpendicular line between the fixed and the rotating heads when both are in the same horizontal plane.

to read as follows:

> The nonrotating header shall be equipped to permit attachment of each hose assembly with individual adjustment for length. When mounted in the whip test machine the projected length of the hose assembly shall be 1.750 ± 0.015 in. less than the straight length. The whip test results are very sensitive to errors in setting this length and measurements shall be taken carefully and the reduction from straight length to projected length on the machine shall be within the limits specified. The projected

---

[6] 1943 Supplement to Book of A.S.T.M. Standards, Part III.

[7] These methods were accepted as tentative by the Society and appear in the 1944 Book of A.S.T.M. Standards, Part III.

[8] 1942 Book of A.S.T.M. Standards, Part III.

length shall be taken parallel to the axis of the rotating head.

Tentative Methods of Testing Automotive Air Brake and Vacuum Brake Hose (**D 622 – 41 T**)[8]—The following revisions have been developed in the same way as the preceding ones on hydraulic brake hose and are very desirable improvements in the methods:

New Section 8.—Add a new Section 8 on cold test to read as follows, renumbering the subsequent sections accordingly:

> 8. *Cold Test.*—The hose shall be conditioned in a cold box in straight position at −40 F. for 72 hr. After conditioning and without removal from the cold box, the hose shall be bent around a mandrel having a diameter ten times the outside diameter of the hose, and shall not break nor crack.

Section 9.—Renumber as Section 10, omit the words "gasoline immersion" from the title of the section, and change the first sentence to read as follows:

> The swelling test on air brake hose shall be conducted in accordance with Section 23 of the Tentative Methods of Testing Rubber Hose (A.S.T.M. Designation: D 380), except that A.S.T.M. precipitation naphtha[a] shall be used as the immersion media.

In the second sentence add the words "and cover" after the word "tube."

Section 11.—Renumber as Section 12 and change "29 in." to read "26 in." of mercury.

Section 13.—Renumber as Section 14 and change the title from "gasoline immersion test" to read "swelling test."

In the third and fourth sentences in Paragraph (*a*) change "gasoline" to read "naphtha," and change the first sentence to read as follows:

> A specimen of vacuum brake hose 12 in. in length shall be filled with A.S.T.M. precipitation naphtha[a] enclosed by means of suitable cork stoppers to prevent loss by evaporation or leakage.

Change the first sentence of Paragraph (*b*) to read as follows: "A steel ball of specified diameter shall be dropped through the specimen." Also delete Table IV.

In Paragraph (*c*) change "29 in." to read "26 in." of mercury.

Tentative Method of Test for Indentation of Rubber by Means of the Durometer (**D 676 – 42 T**):[8, 9]

Section 4 (*c*).—Change from its present form: namely,

> (*c*) *Time of Reading.*—The durometer indentation reading shall be taken as soon as the indicating hand of the dial comes to rest or, if this is not possible, at the moment when a definite change in needle speed is noted.

to read as follows:

> (*c*) *Time of Reading.*—The durometer indentation reading shall be taken exactly 15 sec. after the pressure plate has made contact with the test specimen.

Tentative Specifications for Chloroprene Sheath Compound for Electrical Insulated Cords and Cables (**D 752 – 43 T**) *and* (**D 753 – 43 T**).[6]—In Section 1 on Scope of both of these specifications add "GR-M" after the word "chloroprene," and add the following phrase at the end of the sentence: "at temperatures not lower than −25 C." These changes are considered necessary in order to specify the kind of chloroprene permitted and to limit the use of the compounds to temperature ranges where they remain flexible.

Tentative Specifications for Insulated Wire and Cable: Performance Synthetic Rubber Compound (**D 755 – 43 T**):[6]

Section 2.—Change Note 2 from its present form: namely,

> NOTE 2.—Where this compound is to be used as the insulation of the individual conductor of a jacketed cable and subjected to a second vulcanization, the physical properties of the insulation after the second vulcanization shall be not less than the following:

---

[a] Requirements for this precipitation naphtha are given in Section 4 of the Standard Method of Test for Precipitation Number of Lubricating Oils (A.S.T.M. Designation: D 91).

[9] This method was further revised subsequent to the annual meeting, see Editorial Note, p. 468.

Initial tensile strength, min. psi	600
Elongation at rupture, min., per cent	250
Tensile strength after 48 hr. in oxygen pressure test, min., psi	500

to read as follows:

NOTE 2.—When the insulation has been subjected to a second vulcanization, such as occurs when it is used as the insulation of single conductors under vulcanized jackets, the physical properties shall be not less than the following:

Initial tensile strength, min., psi	600
Elongation at rupture, min., per cent	250
Tensile strength after 48 hr. in oxygen pressure test, min., psi	500

III. ADOPTION OF TENTATIVE STANDARDS AS STANDARD

The committee recommends that the Tentative Methods of Test for Resistance to Light Checking and Cracking of Rubber Compounds (D 518 – 38 T)[8] and for Tear Resistance of Vulcanized Rubber (D 624 – 41 T)[8] be approved for reference to letter ballot of the Society for adoption as standard without revision. Both of these methods have stood without revision for several years and are believed to be in quite general use. Since no comments or criticisms have been received, it is believed that they should be adopted as standard.

The committee also recommends that the Tentative Methods of Sampling and Testing Rubber Latex (D 640 – 41 T) be approved for reference to letter ballot of the Society for adoption as standard with the following revisions:

Title.—Change to read as follows: "Methods of Sampling and Testing Latices of Natural Rubber and Synthetic Rubbers."

Section 1.—Change to read as follows by the addition of the italicized words: "1. These methods are intended for use, as required, in sampling and measuring variability in composition of normal and concentrated rubber latex *and synthetic rubber latices.*"

IV. TENTATIVE STANDARDS CONTINUED AS TENTATIVE WITHOUT REVISION

The committee recommends that all the tentative standards under its jurisdiction not mentioned in this report be continued as tentative without revision. With very few exceptions, these tentative standards, which have been in the tentative status for two years or more, are at the present time actively under consideration. In those cases where revision is not already actually planned, adoption as standard at the present time is consid-

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. NEW TENTATIVE STANDARDS			
Test for Young's Modulus in Flexure of Natural and Synthetic Elastomers at Normal and Subnormal Temperatures[a]	54	7	37
Spec. for Cellular Rubber Products	41	2	55
II. REVISION OF TENTATIVE STANDARDS			
Testing Sponge Rubber Products (D 552 – 43 T)	44	1	53
Testing Automotive Hydraulic Brake Hose (D 571 – 40 T)	35	0	63
Testing Automotive Air Brake and Vacuum Brake Hose (D 622 – 41 T)	33	0	65
Test for Indentation of Rubber by Means of the Durometer (D 676 – 42 T)	57	4	37
Spec. for Chloroprene Sheath Compound for Electrical Insulated Cords and Cables (D 75 – 43 T)	42	0	56
Spec for Chloroprene Sheath Compound for Electrical Insulated Cords and Cables Where Extreme Abrasion Resistance is Not Required (D 753 – 43 T	42	0	56
Spec. for Insulated Wire and Cable: Performance Synthetic Rubber Compound (D 755 – 43 T)	42	0	56
III. ADOPTION OF TENTATIVE STANDARDS AS STANDARD			
Test for Resistance to Light Checking and Cracking of Rubber Compounds (D 518 – 38 T	66	2	30
Test for Tear Resistance of Vulcanized Rubber (D 624 – 41 T)	70	2	26
Sampling and Testing Rubber Latex (D 640 – 41 T), as revised	46	1	44

[a] The classified vote on the adoption as tentative of the Tentative Method of Test for Young's Modulus in Flexure of Natural and Synthetic Elastomers at Normal and Subnormal Temperatures was as follows: Affirmative: 24 producers, 15 consumers, 15 general interests; negative: 3 producers, 1 consumer, 3 general interests.

ered inadvisable because of war conditions and the changing status of the rubber supply with conversion to various synthetic rubbers.

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 135 voting members; 98 members returned their ballots, with the results shown in Table I.

ACTIVITIES OF SUBCOMMITTEES

Technical Committee A on Automotive Rubber (W. J. McCortney, chairman).—During the past year, Technical Committee A has undergone reorganization with respect to both membership and methods of procedure. A new set of rules governing the activities of this committee has been adopted and the committee is now on a regular schedule of bimonthly meetings. Two new permanent sections have been organized, one having jurisdiction over questions of membership and rules governing procedure, the other an editorial section which will review all reports and publications and publicity material other than those with circulation restricted within the committee.

Through its Section III on Hose, revisions have been completed in the specifications and methods of test for air brake and vacuum brake hose (D 622 – 41 T). The revised specifications are being published by the Society of Automotive Engineers and the revisions in the test methods appear earlier in this report. This section is working on hydraulic brake hose and recommended the revisions in Methods D 571 – 40 T—as mentioned earlier in this report, but has not yet reached agreement on the specifications to be referred to the S.A.E. All of the proposed changes have been made necessary by the conversion from natural rubber to synthetic. The section is still working on specifications for coolant hose and is now giving attention to the use of synthetic rubber in this product. Work is also in progress on fuel and oil hose and on windshield wiper hose. All of these types of hose are important for applications on war equipment.

Section IV on Classification and Specifications of Rubber Compounds, which prepared the Specifications for Rubber and Synthetic Rubber Compounds for Automotive and Aeronautical Applications (D 735 – 43 T), has continued work in an effort to develop jointly with Committee D-20 on Plastics, additional tables for these specifications to cover applications of nonrigid plastic compounds which are often used interchangeably with the rubber or synthetic rubber materials for the same purposes. It is hoped that such tables may be completed in the next few months and submitted as proposed revisions in the compound specifications. The section has also been carrying on considerable work on test methods now given in these specifications and has accumulated considerable data on oven aging and fluid aging tests. The section intends to add further requirements and test methods to the specifications as needed and has reserved the following suffix letters for the tests indicated:

G—Tear resistance,
H—Flexing resistance,
J—Abrasion resistance,
K—Adhesion,
L—Water absorption,
M—Inflammability,
N—Impact, and
Z—Special tests of either laboratory or performance types as agreed between the interested parties.

It is not intended to add these suffix letters in the specifications until suitable test methods and proper limiting values have been determined and the section is continuing its work to this end.

As a result of the work of Section VI on Automotive V-Belts, the committee is now certain that synthetic rubbers can be used satisfactorily in V-belts. Service tests are still in progress and results to date are satisfactory. A new universal type of V-belt testing machine has been described to the section and has been built by one of its members. The possibility of standardizing all such test units is to be investigated.

A new Section IX on Hydraulic Brake Cups has already completed specifications on this product made from natural rubber which is still permitted in this application because of its functional importance on military vehicles and work is in progress on the use of synthetic rubber in these cups.

Another new Section X on Gasketing Material is actively at work on specifications covering automotive gaskets. It is expected that this section will be in a position to submit these specification within the next few months.

Subcommittee V on Insulated Wire and Cable (R. A. Schatzel, chairman).—This subcommittee has been very active and has a number of projects under way on the properties of the new synthetic insulating materials and better methods for testing them. Additional tentative specifications are being prepared on synthetic jacket compounds, one to be made from GR-S with a lower tensile strength than at present required by Emergency Specifications ES - 6a and the other to be made from Buna-N which will have superior oil-resisting qualities. It is expected that these specifications will be ready for presentation to the Society in the near future.[10]

Subcommittee XI on Chemical Analysis (S. Collier, chairman).—This subcommittee has been giving attention to methods whereby the synthetic rubber in vulcanized compounds may be determined both as to identity and quantity. Considerable work on this subject has already been done in England and in committees sponsored by the Government. It seems probable that the subcommittee may be able in the near future to recommend suitable tentative methods for this purpose.

Subcommittee XVII on Rubber Products for Absorbing Vibration (L. V. Cooper, chairman).—This subcommittee is investigating the effect on compression set determinations of using molded test specimens instead of the cut specimens required in Section 5 of the Tentative Methods of Test for Compression Set of Vulcanized Rubber (D 395 - 40 T). Many laboratories prefer to mold these specimens but there is as yet no assurance that such a procedure will not affect the results obtained. The subcommittee is also investigating the effect of changing the height and diameter of the specimens. Another project under way is the revision of the Tentative Method of Test for Indentation of Rubber by Means of the Durometer (D 676 - 42 T) to provide for testing at low temperatures. This may involve a somewhat comprehensive investigation of the effect of various temperatures on the results of these tests.

Subcommittee XIX on Test for Properties of Rubber and Rubber-Like Materials on Liquids (J. A. Baty, chairman).—Continuing its work on standardizing the liquids used in immersion tests, this subcommittee has turned its attention to immersion media of the gasoline type after having recommended three standard oils. A great deal of immersion testing in the past has been done in straight-run aviation grade gasoline or in A.S.T.M. precipitation naphtha. These fluids have not been too satisfactory in connection with synthetic rubbers for several reasons, one of which has been the recent tendency to introduce aromatic compounds into fuels used in service with a result that material which was satisfactory in test in the nonaromatic fuel failed in service due to the difference in the nature of the liquid. Another factor which has given continual trouble has been the commercial variation in the petroleum base. It was felt therefore that better results would be obtained if standard immersion media were to be pure chemical compounds rather than commercial fuels. Such immersion media have now been developed in two types, the first representing the "low-swelling" gasolines and the other the "high-swelling" gasolines. For the first of these, diisobutylene with a small amount of an inhibitor has proven satisfactory. The high-swelling liquid consists of 60 per cent of the diisobutylene with the balance made up of definite percentages of benzene, toluene, and xylene. The subcommittee has accumulated considerable data with these fluids and it is anticipated that recommendations for their adoption will be made in the near future.[10] This subcommittee is also working on methods for gum extraction and diffusion in immersion tests and hopes soon to make definite recommendations as to methods of test.

---

[10] See Editorial Note, p. 468.

Subcommittee XXIII on Hard Rubber (W. H. Juve, chairman).—This subcommittee has completed a round-robin test program participated in by 11 laboratories investigating the reproducibility of the tension and the elongation tests according to the procedure in the Tentative Methods of Testing Hard Rubber Products (D 530 – 39 T).[10] Two types of hard rubber compounds were tested, one having high and the other low elongation. Special precautions were taken to insure uniformity of samples and complete records were kept of all test details. The results obtained were more uniform for both stocks than those which the subcommittee has secured in previous tests but there was some indication that variations were introduced by different types of testing machines which gave different rates of load application. Further investigation of this is in progress. The committee is also working on refinement of other procedures in the standard methods under its jurisdiction.

Subcommittee XXIV on Tests for Proofed Fabrics (A. F. Schildhauer, chairman).—After preparing the Tentative Methods of Testing Rubber-Coated Fabrics (D 751 – 43 T), the subcommittee concentrated on other test procedures which should be added to this tentative standard to make it more complete. Attention is being given to additional hydrostatic pressure tests and also to methods for measuring hydrogen permeability.[10] In addition, tests are under consideration for scrub resistance, abrasion resistance, and flexing life, all of which are important for the satisfactory evaluation of a coated fabric. When agreement is reached on any of these methods, it is expected that revisions will be recommended in the present tentative methods.

Subcommittee XXV on Low-Temperature Test for Rubber and Rubber-Like Materials (B. S. Garvey, chairman).—In addition to having completed the proposed Tentative Method of Test for Stiffening of Vulcanized Elastomers at Low Temperatures presented in this report, this subcommittee is giving attention to a revision of the Tentative Method of Test for Brittleness of Nonrigid Plastics (D 746 – 43 T) developed by Committee D-20 on Plastics so that it may be applicable to rubber and synthetic elastomers. For this purpose, a joint section has been organized in cooperation with Committee D-20 and agreement has been reached on the changes desired. This revision is now out to letter ballot in Subcommittee XXV and is expected to be presented to the Society by Committee D-20 with the added endorsement of Committee

D-11. Neither of these two methods of low-temperature testing eliminates the need for the present Tentative Method D 736, the so-called "Thiokol" test, which will be retained for the present. This subcommittee is very much interested in the effect of low temperature on hardness tests and particularly on the use of the Shore durometer under these conditions. It has prepared recommendations which are under consideration by Subcommittee XVII. The subcommittee is also convinced that there is need for a general presentation on the cold conditioning of specimens prior to the application of any specific test procedure. The pretreatments used in low-temperature testing involve exposure of the specimens to a variety of different temperatures for varying times and under a number of other conditions. These variations produce different effects and often profoundly influence the results obtained by the test procedure. Such a discussion of low-temperature conditioning is now in preparation and when completed will be recommended either for incorporation in each of the present low-temperature methods or for publication as a separate tentative method on low-temperature conditioning of rubber and rubber-like materials. The subcommittee has investigated tests for low-temperature compression set and also for fatigue and flexing. The results with compression set were inconclusive and the committee felt that this type of low-temperature testing is not sufficiently needed to justify the work necessary to develop a satisfactory procedure. Fatigue tests at low temperature are of little value because of hysteresis heat effects. When a specimen at low temperature is rapidly bent or deformed, internal heat develops and after a few deformations the specimen is no longer at the low temperature because of slow conduction and radiation of the hysteresis heat. The subcommittee has concluded that if such a test is needed at all, its use would be restricted to very special purposes.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, Simon Collier.
Vice-Chairman, Harry E. Outcault.
Secretary, Arthur W. Carpenter.
Members-at-Large of Advisory Subcommittee:
  W. H. Juve, Consultant.
  A. R. Kemp, Bell Telephone Laboratories.
  T. A. Werkenthin, U. S. Navy, Bur. of Ships.
  L. V. Cooper, Firestone.

This report has been submitted to letter ballot of the committee, which consists of 135 members; 98 members returned their ballots, of whom 83 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the committee,

SIMON COLLIER,
Acting Chairman.

ARTHUR W. CARPENTER,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-11 presented to the Society through Committee E-10 on Standards the following recommendations:

Emergency Alternate Provisions in:

Methods of Testing Rubber Insulated Wire and Cable (D 470 - 41),
Specifications for Insulated Wire and Cable: Heat-Resisting Synthetic Rubber Compound (D 754 - 43 T),
Specifications for Insulated Wire and Cable: Performance Synthetic Rubber Compound (D 755 - 44 T), and

Revision of the Emergency Alternate Provisions in

Specifications for Insulated Wire and Cable: Ozone-Resistant Type Insulation (EA - D 574a).

These recommendations were accepted by Committee E-10 on November 13, 1944, and the new and revised emergency provisions appear in the 1944 Book of A.S.T.M. Standards, Part III.

On December 13, 1944, the Standards Committee accepted the following recommendations submitted by Committee D-11:

Tentative Specifications for:

GR-S (Synthetic Rubber) Sheath Compound for Electrical Insulated Cords and Cables (D 812 - 44 T),

Tentative Methods of Test for:

Resistance of Vulcanized Rubber and Synthetic Elastomers to Crack Growth (D 813 - 44 T),
Hydrogen Permeability of Coated Fabrics (D 815 - 44 T),
Permeability of Vulcanized Rubber or Synthetic Elastomers to Volatile Liquids (D 814 - 44 T),
Rubber Adhesives (D 816 - 44 T),

Revision of Tentative Specifications for:

Cellular Rubber Products (D 798 - 44 T),

Revision of Tentative Methods of:

Test for Changes in Properties of Rubber and Rubber-Like Materials in Liquids (D 471 - 43 T),
Testing Hard Rubber Products (D 530 - 39 T),
Testing Automotive Hydraulic Brake Hose (D 571 - 44 T),
Testing Cellular Rubber Products (D 552 - 44 T),
Test for Indentation of Rubber by Means of the Durometer (D 676 - 44 T), and

Tentative Revision of the Standard Method of:

Test for Accelerated Aging of Vulcanized Rubber by the Oven Method (D 573 - 42).

The new and revised tentatives as well as the tentative revision appear in the 1944 Book of A.S.T.M. Standards, Part III.

REPORT OF COMMITTEE D-12

ON

SOAPS AND OTHER DETERGENTS

Committee D-12 on Soaps and Other Detergents held its annual meeting on March 13 and 14, at the Hotel New Yorker, New York City, with the largest attendance in its history. At some meetings of the sections 40 to 45 people were present. There were a number of visitors, and it would appear that there will be a number of applications for membership on the committee, as the visitors seemed extremely interested in the work.

At the March meeting, the report of the Nominating Committee was adopted, resulting in the re-election of the present officers and Advisory Committee for the ensuing term of two years.

It is with regret that the death of W. H. Tiffany of the U. S. Testing Co. is recorded in this report.

Committee D-12 is cooperating with Subcommittee VII on Accelerated Tests for Protective Coatings of Committee D-1 on Paint, Varnish, Lacquer, and Related Products, with J. C. Harris as the representative of Committee D-12.

The Advisory Committee decided to review the personnel of various sections, looking toward reducing their size, if possible. This will be done by means of a questionnaire to be sent out by the secretary. It also formed a new Section E on Physical Testing, of Subcommittee I, under the chairmanship of J. A. Woodhead to study all physical testing, including performance tests in aqueous and nonaqueous media.

Sections A, B, and C, of Subcommittee II, will be combined as Section A on Soap Specifications under the chairmanship of F. Krassner.

Considerable time was devoted in the section meetings to discussions with J. E. Simpson of the Quartermaster Corps, U. S. Army, regarding modification of the Army and Navy specifications for rosin soaps. It is believed that these discussions were of material assistance, but action was not taken to incorporate the modifications in the D-12 specifications, as the changes may only be of a temporary nature. Mr. Simpson also desired information on fifteen items used in dry-cleaning soaps, for which there are no specifications at present. The committee furnished him with sources of supply for the various items, and will assist him in writing these specifications.

Subsequent to the Annual Meeting, Committee D-12 presented to the Society through Committee E-10 on Standards proposed Emergency Alternate Provisions in the Standard Specifications for Chip Soap (D 496 – 39) and for Powdered Soap (Nonalkaline Soap Powder) (D 498 – 39). These emergency provisions were accepted by Committee E-10 on August 30, 1943, and issued under the designations EA – D 496a and EA – D 498a, respectively. They were published in ASTM BULLETIN, No. 125, December, 1943.

I. NEW TENTATIVE STANDARDS

The committee recommends that the following specifications and methods of test be accepted for publication as tentative:

Tentative Specifications for Liquid Toilet Soap,[1] and

Tentative Methods of Chemical Analysis of Industrial Metal Cleaning Compositions.[1]

II. Revision of Tentative Standards

The committee recommends that the following tentative standards be revised as indicated below and continued as tentative:

Tentative Specifications for Tetrasodium Pyrophosphate (Anhydrous) (**D 595 – 42 T**),[2] revised as follows:

Section 5.—Change to read as follows by the addition of the italicized words: "Material which has picked up sufficient water, *as indicated by loss on ignition*, to reduce the tetrasodium pyrophosphate content to 95 per cent or lower, may be rejected at the option of the purchaser."

Tentative Definitions of Terms Relating to Soaps and Other Detergents (**D 459 – 43 T**),[3] revised as appended hereto[1] by the addition of four new definitions and changes in thirteen of the present definitions referred to under the report of Subcommittee III.

III. Tentative Revision of Standard

The committee recommends for publication as tentative the following revision in the Standard Methods of Sampling and Chemical Analysis of Special Detergents (D 501 – 43):[3]

New Section.—Add a new Section 31 at the end of the methods to read as follows:

31. *Loss on Ignition.*—Weigh 3 g. of the sample into a porcelain crucible which has previously been ignited to constant weight. Heat in a muffle furnace at 400 C. for 2 hr., cool in a desiccator, and weigh. Calculate the loss on ignition as follows:

$$\text{Loss on Ignition, per cent} = \frac{\text{loss in weight}}{\text{weight of sample}} \times 100$$

IV. Adoption of Tentative Standards as Standard

The committee recommends that the following four tentative standards be approved for reference to letter ballot of the Society for adoption as standard:

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. New Tentative Standards			
Spec. for Liquid Toilet Soap....	52	0	7
Chemical Analysis of Industrial Metal Cleaning Compositions.	51	1	7
II. Revision of Tentative Standards			
Spec. for Tetrasodium Pyrophosphate (Anhydrous) (D 595 – 42 T)................	53	1	5
Def. of Terms Relating to Soaps and Other Detergents (D 459 – 43 T)................	55	0	4
III. Tentative Revision of Standard			
Sampling and Chemical Analysis of Special Detergents (D 501 – 43)..................	53	1	5
IV. Adoption of Tentative Standards as Standard			
Spec. for Built Soap, Powdered (Type D) (D 533 – 42 T)......	52	0	7
Spec. for Trisodium Phosphate (D 538 – 43 T)................	55	0	4
Spec. for Compound Chip Soap (with Rosin) (D 690 – 42 T)...	54	0	5
Spec. for Compound Powdered Soap (Granulated, with Rosin) (D 691 – 42 T)...............	54	0	5
V. Adoption as Standard of Tentative Revision of Standard			
Sampling and Chemical Analysis of Soaps and Soap Products D 460 – 42).................	52	0	7

Tentative Specifications for:

Built Soap, Powdered (Type D) (D 533 – 42 T),

Trisodium Phosphate (D 538 – 43 T),

Compound Chip Soap (with Rosin) (D 690 – 42 T), and

Compound Powdered Soap (Granulated, with Rosin) (D 691 – 42 T).

V. Adoption as Standard of Tentative Revision of Standard

The committee recommends that the tentative revision[3] of the Standard Methods of Sampling and Chemical Analysis of Soaps and Soap Products

---

[1] These specifications and methods were accepted as tentative by the Society and appear in the 1944 Book of A.S.T.M. Standards, Part III.

[2] 1942 Book of A.S.T.M. Standards, Part III.

[3] 1943 Supplement to Book of A.S.T.M. Standards, Part III.

(D 460 – 42),[2] issued in June, 1942, be approved for reference to letter ballot of the Society for adoption as standard.

VI. EMERGENCY ALTERNATE PROVISIONS

No changes are recommended by Committee D-12 at this time in the Emergency Alternate Provisions under its jurisdiction.[4]

The recommendations appearing in this report have been submitted to letter ballot of the committee which consists of 87 members; 59 members returned their ballots with the results shown in Table I.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Methods of Testing (J. B. Crowe, chairman):

Section A on Soaps (M. L. Sheely, chairman) has recommended that the tentative revision of Methods D 460 be adopted as standard as covered earlier in this report. The program of this section for the ensuing year consists of two parts, first, studies on the determination of free caustic alkali and carbonates for potash soaps, and second, studies on the analysis of mixtures of soaps and synthetic detergents. From this work suitable methods for these determinations will be evolved.

Section B on Sulfonated Detergents (Ralph Hart, chairman) is working in cooperation with a similar committee of the American Association of Textile Chemists and Colorists, and a committee of the American Oil Chemists' Society.

Second C of Subcommittee I and Section D of Subcommittee II on Dry-Cleaning Detergents (Mary Deck Hale, chairman) have been reorganized under Dr. Hale's leadership. This section discussed the question of analytical methods for determining the composition of dry-cleaning soaps. Available methods will be collected and studied by this committee, looking toward the establishment of standard methods of analysis for this type of detergent. It will also work on performance tests in nonaqueous medium. This section assisted J. E. Simpson, of the Quartermaster Corps, in the preparation of specifications for fifteen dry-cleaning products which he will use in connection with Federal specifications and with the further assistance of members of the committee.

Section D on Special Detergents (W. H. Koch, chairman) prepared the method for loss on ignition on tetrasodium pyrophosphate which is recommended for publication as a tentative revision of the Standard Methods of Sampling and Chemical Analysis of Special Detergents (D 501 – 43).

Subcommittee II on Specifications (F. W. Smither, chairman):

Section A on Textile Soaps and Section C on Straight Soaps, under the leadership of C. L. Nutting and Israel Katz, respectively, have cooperated in the preparation of the new Specifications for Liquid Toilet Soap[1] which are recommended for publication as tentative. The sections also discussed fig soaps and tall oil soaps, but no action was taken on them at this time.

Section B on Built Soaps (Frederick Krassner, chairman) recommended that the Tentative Specifications for Built Soap, Powdered (Type D) (D 533 – 42 T), for Compound Chip Soap (with Rosin) (D 690 – 42 T), and for Compound Powdered Soap (Granulated, with Rosin) (D 691 – 42 T) be adopted as standard.

The section discussed with J. E. Simpson, of the Quartermaster Corps, specifications for an all purpose soap and General Issue soap. Any changes made by the Quartermaster Corps will be considered by the committee at its next meeting.

Section E on Sulfonated Detergents

---

[4] See Editorial Note, p. 473.

(J. B. Crowe, chairman) reported that the General Dyestuffs Corp. has developed a new type of soil cloth to be used for evaluating detergents for use in laundry operations. These samples will be sent out to the members for test.

Section F on Special Detergents (C. C. Zeigler, chairman) recommended that the Tentative Specifications for Trisodium Phosphate (D 538 – 43 T) be adopted as standard, and that the Tentative Specifications for Tetrasodium Pyrophosphate (Anhydrous) (D 595 – 42 T) be revised as indicated earlier in this report.

The section will consider specifications for potassium carbonate, potassium hydroxide, sodium bicarbonate, sodium orthosilicate, and borax, during the year.

Section G on Metal Cleaners (J. C. Harris, chairman) recommended that the Proposed Methods of Chemical Analysis of Industrial Metal Cleaning Compositions,[1] which have been published as information since 1942, be accepted for publication as tentative, as mentioned earlier in this report.

Subcommittee III on Definitions (C. A. Marlies, chairman):

This committee has received a number of criticisms of the Tentative Definitions of Terms Relating to Soaps and Other Detergents (D 459 – 43 T), particularly from members of Committee E-8 on Nomenclature and Definitions and recommends that thirteen of the definitions be revised, namely, those for alkali detergents, anhydrous soap, blended soap, drycleaning and drycleaning soap, soap powder, soil redeposition, straight soap, synthetic detergents, washing, waterbreak, wet cleaning, and wetting agent. It also recommended the addition of four new definitions for anionic detergent, cationic detergent, surface active agent, and titre be added, as covered earlier in this report.

Subcommittee IV on Papers and Publications (W. H. Koch, chairman):

The subcommittee has written an article on "The Analysis of Commercial Anhydrous Tetrasodium Pyrophosphate," which will be published in the near future.

Last year Messrs. J. C. Harris and R. B. Mears prepared "An Annotated Bibliography of Aluminum Cleaning." This year they have prepared a supplement under the same title, covering papers published in 1943.[5]

Mr. Harris and his section have prepared a paper entitled "Corrosion Testing of Water Soluble Aluminum Cleaners," which will appear in a forthcoming issue of the ASTM BULLETIN.[6]

W. G. Morse presented a draft of a paper on "Cleaning and Cleaning Materials" before the subcommittee. As a result of the discussion which ensued the paper is to be revised and rewritten and again submitted for further comment.

This report has been submitted to letter ballot of the committee which consists of 87 members; 59 members returned their ballots, of whom 59 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the committee,

H. P. TREVITHICK,
Chairman.

B. S. VAN ZILE,
Secretary.

---

[5] Published in two parts in ASTM BULLETIN, No. 120, January, 1943, and No. 121, March, 1943.

[6] Published in ASTM BULLETIN No. 129, August, 1944, p. 21.

EDITORIAL NOTE

Subsequent to the Annual Meeting Committee D-12 recommended to Committee E-10 on Standards that the Emergency Alternate Provision in the Standard Specifications for Built Soap, Powdered (EA – D 533) be withdrawn. This recommendation was accepted by Committee E-10 on August 28, 1944.

REPORT OF COMMITTEE D-13
ON
TEXTILE MATERIALS

Committee D-13 on Textile Materials held two meetings during the year in New York, N. Y.: a fall meeting October 20 to 22, 1943, and a spring meeting March 8 to 10, 1944. The attendance at these two meetings, including guests, was 224 and 256, respectively, which exceeded any previously reported attendance. Of the 27 subcommittees and sections of Committee D-13 which deal with standards, 13 held sessions at the fall meeting and 20 at the spring meeting.

Society appointment of representatives from the membership of Committee D-13 were as follows: H. J. Ball, with A. G. Ashcroft as alternate, to the Inter-Society Council for Textile Research, a newly-formed organization to correlate the textile research activities of the member national textile societies and associations.

Werner von Bergen has been appointed to represent Committee D-13 on an advisory Committee of the Boston Wool Trade Association which is to look into the desirability of establishing a wool testing laboratory.

The committee is pleased to record the names of two of its esteemed members who have been given places of prominence in Society affairs this year; Dean Harvey, who has served as President of the Society, and Harold DeWitt Smith, who was selected to deliver the 1944 Edgar Marburg Lecture.

At the spring meeting, Gertrude G. Whitcomb was elected an honorary member of the committee in recognition of her faithful devotion to the committee's interests for 18 years and she was presented with a beautifully designed sheepskin scroll appropriately engrossed.

Consideration is being given to extending the scope of the committee's activities and to other changes designed to place the committee in the best possible position to meet the changing trends in new textile fibers, fiber mixtures, and products. One step in this direction has been to change the scope of Subcommittee A-2, Section I on Rayon to include all chemically produced organic type fibers.

EMERGENCY ALTERNATE PROVISIONS

An Emergency Alternate Provision in the Standard Methods of Testing and Tolerances for Knit Goods (D 231 – 39), permitting the use of a new type of condenser as a substitute for that now specified in an effort to conserve block tin tubing, was accepted by Committee E-10 on Standards on April 13, 1944, and has been issued under the designation EA – D 231.

RECOMMENDATIONS AFFECTING STANDARDS

Committee D-13 is recommending the revision of two tentative standards the revision of eleven standards for immediate adoption, the tentative revision of three standards, the adoption as standard of seven tentative standards and three tentative revisions of standards, and the reapproval of nine standards which have stood six years or more without revision.

The revisions being presented are included in detail in the Appendix and are accompanied, where necessary, by brief statements of the reasons for such revisions. The standards affected are listed in Table I and are also referred to under subcommittee activities.

These recommendations have been

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. REVISION OF TENTATIVE STANDARDS			
Testing and Tolerances for Glass Yarn (D 578 – 40 T)	27	0	90
Def. of Terms Relating to Textile Materials (D 123 – 43 T)	81	1	35
II. REVISION OF STANDARDS, IMMEDIATE ADOPTION			
Def. of Terms Relating to Textile Materials (D 123 – 42)	91	0	26
Testing and Tolerances for Cotton Yarns (D 180 – 42)	67	0	50
Testing and Tolerances for Continuous Filament Rayon Yarns (D 258 – 42)	57	1	59
Testing and Tolerances for Woolen Yarns (D 403 – 38)	52	0	65
Testing and Tolerances for Worsted Yarns (D 404 – 38)	51	0	66
Test for Fineness of Wool (D 419 – 37)	52	0	65
Testing and Tolerances for Woven Glass Fabrics (D 579 – 43)	30	0	87
Testing and Tolerances for Woven Glass Tapes (D 580 – 43)	28	0	89
Testing and Tolerances for Woven Glass Tubular Sleeving and Braids (D 581 – 43)	27	0	90
Spec. for Tolerances for Numbered Cotton Duck (D 230 – 27)	43	0	74
Spec. and Test for Asbestos Roving for Electrical Purposes (D 375 – 42)	30	0	87
III. TENTATIVE REVISIONS OF STANDARDS			
Testing and Tolerances for Tire Cord, Woven and on Cones (D 179 – 42)	36	1	80
Testing Wool Felt (D 461 – 40, ASA L 16.1 – 1942)	41	0	76
Spec. for Textile Testing Machines (D 76 – 42; L 15.1 – 1943)	71	0	46
IV. ADOPTION OF TENTATIVE STANDARDS AS STANDARD			
Testing and Tolerances for Woven Tapes (D 259 – 42 T)	36	0	81
Testing and Tolerances for Certain Wool and Part Wool Fabrics (D 462 – 42 T)	47	0	70
Test for Commercial Weight of Rayon Staple (D 540 – 43 T)	46	1	70
Testing Asbestos Tubular Sleeving (D 628 – 41 T)	27	0	90
Testing and Tolerances for Certain Fine Staple Cotton Gray Goods (D 679 – 42 T)	45	0	72
Testing and Tolerances for Certain All-Cotton and Cotton-and-Rayon Fine Fancy Goods (D 680 – 42 T)	43	0	74
Def. of Terms Relating to Textile Materials (D 123 – 43 T)	96	0	21
V. ADOPTION AS STANDARD OF TENTATIVE REVISIONS OF STANDARDS			
Testing and Tolerances for Spun Rayon Yarns and Threads (D 507 – 42)	52	0	65
Testing Wool Felt (D 461 – 40); L 16.1 – 1942)	40	0	77
Spec. and Test for Asbestos Tape for Electrical Purposes (D 315 – 41)	32	0	85
VI. REAFFIRMATION OF STANDARDS			
Spec. and Test for Tire Fabrics Other than Cord Fabrics (D 122 – 37)	49	0	68
Spec. for 0.007-in. Cotton Tape for Electrical Purposes (D 335 – 36)	48	0	69
Spec. and Test for Holland Cloth (D 376 – 35)	50	0	67
Testing and Tolerances for Certain Light and Medium Weight Cotton Fabrics (D 274 – 36)	68	0	49
Determining Relative Humidity (D 337 – 34)	86	0	31
Test for Colorimetric Determition of Small Amounts of Copper and Manganese in Textiles (D 377 – 37)	58	1	58
Test for Strength of Rayon Woven Fabric When Wet (D 415 – 38)	59	0	58
Test for Colorfastness of Dyed or Printed Wool, Silk, or Rayon Fabric to Laundering or Domestic Washing (D 436 – 37)	64	0	53
Test for Shrinkage in Laundering of Woven Cotton Cloth (D 437 – 36)	64	0	53

submitted to letter ballot of the committee which consists of 281 members, the results being shown in Table I.

ACTIVITIES OF SUBCOMMITTEES

The recommendations being submitted indicate that the various subcommittees and sections have been quite active during the year. Many important projects are under consideration and are mentioned briefly in the following summary of subcommittee activities.

Subcommittee A-1 on Cotton and its Products (K. B. Cook, chairman):

Section I on Cotton (M. E. Campbell, chairman) recommends that the Tentative General Methods of Testing Cotton Fibers (D 414 – 40 T) be continued as tentative pending further study of the need of modification of some of the methods in view of recent developments.

Section II on Cotton Yarns and Threads (O. G. Edwards, chairman) recommends for immediate adoption a revision in the Standard General Methods of Testing and Tolerances for Cotton Yarns (D 180 – 42) to specify in conditioning that equilibrium be approached from the dry side, as given in the Appendix.

The section also recommends that the Standard Methods of Testing and Tolerances for Cotton Sewing Threads (D 204 – 42) be editorially revised as indicated in the Appendix.

Section III on Light and Medium Weight Cotton Woven Fabrics (R. T. Fisher, chairman) recommends the adoption as standard of the Tentative Methods of Testing and Tolerances for Certain Fine Staple Cotton Gray Goods (D 679 – 42 T) and for Certain All-Cotton and Cotton-and-Rayon Fine Fancy Goods (D 680 – 40 T).

The section has reviewed the Standard Methods of Testing and Tolerances for Certain Light and Medium Weight Cotton Fabrics (D 274 – 36) and the Standard Method of Test for Shrinkage in Laundering of Woven Cotton Cloth (D 437 – 36) and finds them in accord with present practice and recommends their reapproval.

Section IV on Tire Fabrics (Martin Castricum, chairman) recommends for publication as tentative a revision of the Standards Methods of Testing and Tolerances for Tire Cord, Woven and on Cones (D 179 – 42) to provide methods of test for the determination of yards per pound and verification of elongation recorded by the pendulum type cord testing machine, as given in the Appendix.

The section has reviewed the Standard Specifications and Methods of Test for Holland Cloth (D 376 – 35) and for Tire Fabrics Other than Cord Fabrics (D 122 – 37) and finds them in accord with present practice and recommends their reapproval.

The section is actively engaged in the study of rayon cord fatigue testing, and modifications of present methods of testing cotton tire cord to make them applicable to the testing of rayon cord.

Section V on Heavy Cotton Woven Fabrics (B. L. Whittier, chairman) recommends for immediate adoption a revision of the Standard Specifications for Tolerances for Numbered Cotton Duck (D 230 – 27) which will now cover numbered cotton duck and army duck fabrics.[1]

The section is collecting data looking toward establishing a moisture regain value for heavy cotton woven fabrics.

Section VI on Narrow Fabrics (F. S. Mapes, chairman) recommends for adoption as standard the Tentative Methods of Testing and Tolerances for Woven Tapes (D 259 – 42 T).

The section has reviewed the Standard Specifications for 0.007-in. Cotton Tape for Electrical Purposes (D 335 – 36) and finds them in accord with present practice and recommends their reapproval.

Subcommittee A-2 on Rayon and its Products (A. M. Tenney, chairman):

Section I on Rayon (J. B. Goldberg, chairman) recommends for immediate adoption as standard a revision of the Standard Methods of Testing and Tolerances for Continuous Filament Rayon Yarns (D 258 – 42) to specify rate of loading and provide a method for wet testing of filament yarns for strength. The present tentative revision of this standard is incorporated in the proposed revision.

Section II on Rayon Fabrics (C. W. Dorn, chairman) has reviewed the Standard Method of Test for Strength of Rayon Woven Fabric When Wet (D 415 – 38) and finds it in accord with present practice and recommends its reapproval.

Section III on Rayon Staple and Spun Rayon Yarns (K. B. Cook, chairman) recommends the adoption as standard of the tentative revision[2] of the Standard Methods of Testing and Tolerances for Spun Rayon Yarns and Threads (D

---

[1] These revised specifications were adopted by the Society and appear in the 1944 Book of A.S.T.M. Standards, Part III, p. 760.

[2] 1943 Supplement to Book of A.S.T.M. Standards, Part III.

507 – 42), with an editorial change in the heading to read "Appearance Grades" instead of "Grades." An editorial addition will also be made under the Section on Tolerances providing for a new Section 6 reading as follows: "6. The appearance of the yarn shall be at least equal to that of the appearance grade specified."

The section also recommends that the Tentative Method of Test for Commercial Weight of Rayon Staple (D 540 – 43 T) be adopted as standard and incorporated in Standard Methods D 540.

Subcommittee A-3 on Wool and its Products (A. G. Ashcroft, chairman):

Section I on Wool (Werner von Bergen, chairman) recommends for immediate adoption a revision of the Standard Methods of Test for Fineness of Wool (D 419 – 37) to provide a method for determining fineness of wool in yarns and fabrics, as given in the Appendix.

The section recommends that the tentative revision of the Standard Specifications and Methods of Test for Fineness of Wool Tops (D 472 – 41), issued in 1942, which provides for requirements for wool tops, grades 48's to 36's, be continued as tentative pending further revision.

The section is conducting interlaboratory studies of the sampling of fleeces and the various methods of measuring fineness.

Section II on Felt (G. H. Harnden, chairman) recommends the adoption as standard of the tentative revision of the Standard Methods of Testing Wool Felt (D 461 – 40) which provides methods for the determination of water shrinkage and thickness swell.

The section recommends for publication as a tentative revision of Standard Methods D 461 a section on definitions and a method for the determination of acid in felt as given in the Appendix.

The section is developing a method for measuring air flow resistance of filter felts. Studies are being conducted on machines for evaluating hardness of felt, a method for determining flame resistance, and the development of specifications for felt.

Section III on Woolen and Worsted Yarns (Fred Noechel, chairman) recommends for immediate adoption revisions in the Standard Methods of Testing and Tolerances for Woolen Yarns (D 403 – 38) and for Worsted Yarns (D 404 – 38) to provide a method for determining twist in single yarns in plied yarns, and the addition of a definition of wool.

The section is studying the determination of the number of samples required for the various tests in Standard Methods D 403 and D 404.

Section IV on Pile Floor Coverings (J. N. Dow, chairman) is continuing its studies of several important problems, such as evaluation of resistance of pile floor coverings to matting, correlation of service tests on part-rayon pile fabrics with laboratory wear testers, and sampling method for use in determination of pile fiber content.

Section V on Woolen and Worsted Fabrics (J. N. Dalton, chairman) recommends the adoption as standard of the Tentative Methods of Testing and Tolerances for Certain Wool and Part Wool Fabrics (D 462 – 42 T).

Subcommittee A-4 on Asbestos and its Textile Products (F. S. Mapes, chairman):

This subcommittee recommends for immediate adoption a revision in the Standard Specifications and Methods of Test for Asbestos Roving for Electrical Purposes (D 375 – 42) which provides for additional data on yards per pound requirements, sampling procedure, and number of tests.

The subcommittee recommends for adoption as standard the Tentative Methods of Testing Asbestos Tubular

Sleeving (D 628 - 41 T) and the tentative revision of the Standard Specifications and Methods of Test for Asbestos Tape for Electrical Purposes (D 315 - 41), which specifies the dead weight dial micrometer method for measurement of thickness.

The subcommittee also recommends that the Standard Specifications and Methods of Test for Asbestos Yarns (D 299 - 42) be editorially revised as given in the Appendix.

The subcommittee recommends that the Tentative Specifications for Woven Asbestos Cloth (D 677 - 42 T) be continued as tentative pending a further study of the data on physical properties and that Emergency Alternate Provisions EA - D 375 be continued in its present form pending a further study of the evaluation of the electrical properties of ferrous and non-ferrous rovings.

Subcommittee A-5 on Bast and Leaf Fibers and Their Products (S. J. Hayes, chairman):

This subcommittee recommends that the Tentative Methods of Testing and Tolerances for Jute Rove and Plied Yarn for Electrical and Packing Purposes (D 681 - 42 T) be continued as tentative pending further study of the method for the determination of extractable matter.

Subcommittee A-6 on Household and Garment Fabrics (Ruth O'Brien, chairman):

This subcommittee recommends that the Tentative Specifications for Bleached Wide Cotton Sheeting (D 503 - 40 T), for All Wool, All Cotton, and Wool and Cotton Blanketing (Household) (D 576 - 40 T) for Bleached Cotton Broadcloth (D 504 - 41 T), for Medium-Weight Cotton Corduroy Fabrics (D 625 - 41 T), and for Finished, All-Cotton, Upholstery Tapestries (D 678 - 42 T) be continued as tentative due to the shifting qualities of consumers' textiles resulting from the present shortages of raw materials, manpower, and machinery. The war situation makes it impossible to obtain the data needed as a basis for the formulation of specifications for fabric for normal peacetime use.

Subcommittee A-8 on Glass Fiber and Its Products (Dean Harvey, chairman):

This subcommittee recommends a revision in the Tentative Methods of Testing and Tolerances for Glass Yarn (D 578 - 40 T) to provide a method for the determination of yards per pound, as given in the Appendix.

The subcommittee is also recommending for immediate adoption revisions in the Standard Methods of Testing and Tolerances for Woven Glass Fabrics (D 579 - 43), for Woven Glass Tapes (D 580 - 43), and for Woven Glass Tubular Sleeving and Braids (D 581 - 43) which provide for a change in temperature requirement for the determination of glass content, restricting measurement of thickness to method C in case of dispute, specification of the pendulum-type tester for strength tests, and the raveled strip method for glass fabrics.

Subcommittee B-1 on Methods and Machines (W. D. Appel, chairman):

Section I on Methods (W. D. Appel chairman) recommends that the Tentative Methods of Quantitative Analysis of Textiles (D 629 - 42 T), and the Tentative Method of Test for Colorfastness to Atmospheric Gases of Dyed Cellulose Acetate Rayon (D 682 - 42 T) be continued as tentative pending further revision.

This section has approved, as an emergency alternate provision, a new type of extraction apparatus made of tinned copper for grease determination in the Standard Methods of Testing and Tolerances for Knit Goods (D 231 - 39). As mentioned earlier in this report, this emergency provision was issued in an effort to conserve block tin tubing.

Section II on Machines (H. J. Ball, chairman) recommends for publication as tentative a revision of the Standard Specifications for Textile Testing Machines (D 76 – 42) which provides more definite specifications for the types of machines and their operation, and a general basis for verification of the testing machines for accuracy.

Section III on Humidity (R. H. Brown, chairman) has reviewed the Standard Method of Determining Relative Humidity (D 337 – 34) and finds it in accord with present practice and recommends its reapproval.

Subcommittee B-2 on Nomenclature and Definitions (A. G. Scroggie, chairman):

This subcommittee recommends that the Tentative Definitions of Terms Relating to Textile Materials (D 123 – 43 T) be adopted as standard and incorporated in Standard Definitions D 123.

The subcommittee is recommending an editorial rearrangement of Standard Definitions D 123, the Glossary of Terms and its Supplements, which provides for the division of Standard D 123 into Part A on Definitions and Part B on Fibers, and the appending of the Glossary and its Supplements to the standard. The standard as thus revised and rearranged is appended hereto.[3]

The subcommittee also recommends for publication as tentative several new proposed definitions of terms relating to textile materials, as appended hereto.[3]

This subcommittee has been actively engaged in formulating a Universal Yarn Numbering System, designated as "Grex." The system has received wide publicity in the ASTM BULLETIN[4] and in several textile journals. It will be published as a proposed recommended procedure for yarn numbering in the 1944 edition of the compilation of A.S.T.M. Standards on Textile Materials

Subcommittee B-4 on Bleaching, Dyeing, and Finishing (W. M. Scott, chairman; J. Robert Bonnar, acting chairman):

This subcommittee recommends that the following tentative standards be continued as tentative:

Tentative Specifications for:

Fire-Resistant Properties of Treated Textile Fabrics (D 626 – 41 T),

Tentative Methods of Test for:

Volumetric Determination of Small Amounts of Copper in Textiles (D 463 – 37 T),
Apparent Fluidity of Dispersions of Cellulose Fibers in Cuprammonium Hydroxide (D 39 – 40 T),
Resistance of Textile Fabrics to Water (D 583 – 40 T),
Resistance of Textile Fabrics and Yarns to Insect Pests (D 582 – 41 T),
Evaluating Compounds Designed to Increase Resistance of Fabrics and Yarns to Insect Pests (D 627 – 41 T),
Identification of Finishes on Textiles (D 683 – 42 T), and
Resistance of Textile Fabrics to Microorganisms (D 684 – 42 T).

Specifications D 626 are being continued as tentative pending a further check. Criticisms have been received of Methods D 463, D 539, and D 683 and it is planned to give them further study. Revisions in Methods D 583, D 582, D 627, and D 684 are now under consideration.

This subcommittee has reviewed the Standard Methods of Test for Colorimetric Determination of Small Amounts of Copper and Manganese in Textiles (D 377 – 37) and for Colorfastness of Dyed or Printed Wool, Silk, or Rayon Fabrics to Laundering or Domestic Washing (D 436 – 37), and finds them in accord with present practice and recommends their reapproval.

---

[3] These definitions were accepted by the Society and appear in the 1944 Book of A.S.T.M. Standards, Part III.

[4] A. G. Scroggie, "'Grex' Universal Yarn Numbering System," ASTM BULLETIN No. 127, March, 1944, p. 44.

Subcommittee B-5 on Sampling, Presentation, and Interpretation of Data (O. P. Beckwith, chairman):

This subcommittee is actively engaged in an educational program to stimulate interest in methods of quality control and their application. It is developing plans along three general lines: (*1*) The formulation of a procedure in specification writing, by developing a particular textile test procedure into a model specification with a clear statement of the principles involved; (*2*) setting up a small board of review to which any subcommittee could submit methods in process of development for advice; (*3*) at each meeting having one or more members describe some of their experiences in the field of statistical control. Army representatives will continue to be invited to participate.

The following officers were elected at the March, 1944, meeting for the two-year period from June, 1944, to June, 1946:

Chairman, H. J. Ball.
First Vice-Chairman, A. G. Ashcroft.
Second Vice-Chairman, A. G. Scroggie.
Secretary, W. H. Whitcomb.

This report has been submitted to letter ballot of the committee which consists of 281 members; 117 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

H. J. BALL,
Chairman.

W. H. WHITCOMB,
Secretary.

APPENDIX

RECOMMENDATIONS AFFECTING STANDARDS FOR TEXTILE MATERIALS

In this Appendix are given proposed revisions in certain standards and tentative standards covering textile materials which are referred to earlier in this report.[1] These standards and tentative standards appear in their present form either in the 1942 Book of A.S.T.M. Standards, Part III, or the 1943 Supplement, Part III, as indicated by the final number in the A.S.T.M. designation.

REVISION OF TENTATIVE STANDARD

Tentative Methods of Testing and Tolerances for Glass Yarn (D 578 - 40 T):

New Section 9.—Add a new Section 9 on determination of yards per pound to read as follows, renumbering the subsequent sections accordingly:

9. *Yards per Pound:* (*a*) *Sampling.*—Each individual container shall be sampled by selecting at random 10 per cent of the packages. In no case shall the number of packages selected be less than three.

(*b*) *Test Specimens.*—The length of the test specimen taken from each of the sample packages shall be in accordance with the following requirements:

Specified Weight, yd. per lb.	Specimen Length, yd.
1 to 100, excl.	3
100 to 1000, excl.	9
1000 to 10,000, excl.	30
10,000 to 100,000, excl.	240

(*c*) *Weighing.*—Each test specimen shall be weighed separately on a balance which is accurate to within 0.25 per cent of the weight, and the average weight of the specimens determined.

(*d*) *Calculation.*—The yards per pound shall be calculated from the length and average weight of the specimens by either of the following formulas:

$$Y = \frac{453.6 \times L}{W_1}$$

$$Y = \frac{7000 \times L}{W_2}$$

where:

Y = yards per pound,
L = specimen length in yards,
W_1 = average weight of specimens in grams, and
W_2 = average weight of specimens in grains.

Section 12.—Change the second sentence to read as follows by the addition of the italicized words and figures and the omission of those in brackets: "The specimens shall then be placed in a ventilated oven and heated for 1 hr. at a temperature of [425 to 500 C. (797 to 932 F.)] *500 ± 20 C. (932 ± 36 F.).*"

REVISION OF STANDARDS, IMMEDIATE ADOPTION

Standard General Methods of Testing and Tolerances for Cotton Yarns (D 180 - 42):

Section 2 (*b*).—Add the following sentence at the end of this paragraph: "Moisture equilibrium shall be approached from the dry side (not moisture free)."

Standard Methods of Testing and Tolerances for Continuous Filament Rayon Yarns (D 258 - 42):

Section 19.—Delete this section in its present form and substitute the following, renumbering subsequent sections accordingly:

---

[1] See p. 474.

A. PREFERRED METHOD

19. *Breaking Strength, Dry, Single Strand.*—The results obtained by this method are the breaking loads required to rupture the single strands. They may be expressed as breaking strength in grams, or in terms of tenacity, or in terms of tensile strength in accordance with Section 22.

20. *Test Specimens.*—(*a*) The specimens of yarn for strength determination shall be drawn from the side of the package instead of over the top, to avoid change in twist.

(*b*) An initial tension shall be applied to the specimen before gripping the specimen in the clamps. This tension shall be sufficient to remove any slack or kinks, but not great enough to produce any appreciable elongation.

(*c*) Tests in which the specimen breaks at the edge of the jaws shall be rejected.

21. *Apparatus.*—The testing machine for strength determination shall conform to the Standard Specifications for Textile Testing Machines (A.S.T.M. Designation: D 76). Either the pendulum type (constant-rate-of-traverse) or the constant rate-of-load type may be used.

(*a*) *Pendulum Type Testers.*—The machine shall be of suitable capacity as defined in A.S.T.M. Specifications D 76. The speed of the pulling clamp shall be 12 ± ½ in. per min. The distance between the clamps shall be 18 in.

(*b*) *Constant Rate-of-Load Testers.*—The distance between the clamps shall be 20 in. The rate of loading shall be in accordance with the following table:

Group	Tenacity, g. per denier	Rate of Loading, g. per denier per min.
I	1.75 and under	2
II	Over 1.75 to 3.5, incl.	4
III	Over 3.5	12

NOTE.—When a direct comparison of two specimens falling in different groups is required, both specimens shall be tested at the rate specified for the weaker specimen.

(*c*) The capacity of constant rate-of-load testers shall be such that when testing yarns breaking above 0.6 g. per denier, the maximum effective load exerted by the carriage shall be not greater than 3.5 times the breaking load of the specimen.

22. *Expression of Results:* (*a*) *Breaking Strength.*—The breaking strength shall be expressed in grams.

(*b*) *Tenacity.*—The tenacity shall be expressed in grams per denier as calculated by dividing the breaking strength by the denier of the unstressed specimen.

(*c*) *Tensile Strength.*—The tensile strength shall be expressed as breaking strength per unit cross-sectional area as calculated by dividing the breaking strength by the cross-sectional area of the unstressed specimen.

23. *Breaking Strength, Wet, Single Strand:* (*a*) *Test Specimens.*—The required number of test specimens shall be cut from the sample in approximately 30-in. lengths.

(*b*) *Procedure.*—The test specimens shall be immersed in distilled water for a minimum period of 2 min. for viscose or cuprammonium rayon, and 10 min. for acetate rayon (Note 1). A single strand shall be carefully withdrawn from the water bath, inserted in the clamps of the testing machine and broken in accordance with Section 21. Care shall be exercised in removing the specimen from the water bath and clamping it in the testing machine to avoid stretching (Note 2).

NOTE 1.—The time of immersion must be sufficient to wet out the specimens thoroughly, as indicated by no further loss of strength following longer periods of immersion. The time may have to be prolonged on specimens treated with water-repellant or water-resistant materials. For yarns not readily wet out with water, a penetrating agent such as neutral soap or sulfated oil may be added to the water bath. The amount of such agent used shall not exceed that required to secure the maximum rate of wetting out, and no agent shall be used that will affect the normal physical properties of the yarn.

NOTE 2.—If a number of specimens cling together in the bath, they can be dispersed by gently raising and lowering the group in the water, thus permitting a single end to be withdrawn without strain.

Standard Methods of Testing and Tolerances for Woolen Yarns (D 403 – 38):

New Section 6.—Add a new Section 6 on definition of wool to read as follows, renumbering the subsequent sections accordingly:

6. *Wool.*—The word wool shall be used in these methods in the generic sense and includes *reprocessed* and *reused* wool as defined in the Wool Products Labeling Act:

(*a*) *Wool.*—The term "wool" means the fibers from the fleece of the sheep or lamb, or hair of the angora or cashmere goat (and may include the so-called specialty fibers from the hair of the camel, alpaca, llama, and vicuna) which has never been reclaimed from any woven or felted wool product.

(*b*) *Reprocessed Wool.*—The term "reprocessed wool" means the resulting fiber when wool has been woven or felted into a wool product which without ever having been utilized in any way by the ultimate consumer, subsequently has been made into a fibrous state.

(*c*) *Reused Wool.*—The term "reused wool" means the resulting fiber when wool or reprocessed wool has been spun, woven, knitted, or felted into a wool product which, after having been used in any way by the ultimate consumer, subsequently has been made into a fibrous state.

Section 23.—Add a new Paragraph (*c*) on twist of singles in plied yarn to read as follows:

(*c*) *Single Yarn in Plied Yarn.*—The twist in the plied yarn shall be removed in accordance with Paragraph (*b*) with the following exceptions. The clamps shall be set approximately 4 in. apart and no tension applied. After removal of the ply twist and with the clamps still closed, all plies except one shall be cut off at each end. The clamps shall be adjusted to draw the yarn just taut enough to prevent sagging, and the distance between the clamps shall then be determined. The twist in the single yarn shall be determined as in Paragraph (*a*).

Standard Methods of Testing and Tolerances for Worsted Yarns (D 404 – 38):

New Section 6.—Add the same new Section 6 as is recommended above in Method D 403.

Section 23.—Add the same new Paragraph (*c*) as is recommended above in Method D 403.

Standard Methods of Test for Fineness of Wool (D 419 – 37).

Section 3.—Change from its present form to read as follows:

3. *Sampling:* (*a*) *Loose Wool.*—The samples shall be carded three times or gilled 15 times. From the resultant sliver, two to sixteen test specimens of approximately 120 fibers each shall be selected for measurement. Test specimens from the same carded or gilled sliver shall be taken at least 10 in. apart in the length direction or at least 0.5 in. apart across the width of the sliver to avoid measuring the same fiber twice. The number of specimens and the number of measurements required for each fineness range shall be as specified in Table I.

(*b*) *Top.*—The sampling procedure and the number of measurements shall be in accordance with Sections 4 and 5 of the Standard Specifications and Methods of Test for Fineness of Wool Tops (A.S.T.M. Designation: D 472).

(*c*) *Roving.*—The samples shall be drawn from several packages or jack spools to represent a good average of the lot to be tested. Test specimens from the same roving shall be taken 5 to 10 in. apart depending on the length of the longest fibers present. The number of test specimens and the number of measurements for the fineness range of the sample shall be in accordance with the requirements specified in Table I.

TABLE I.—NUMBER OF TEST SPECIMENS AND MEASUREMENTS REQUIRED.

Fineness Range, microns	Number of Test Specimens	Number of Fibers Measured per Specimen	Total Number of Fibers Measured
18 and under	2	100	200
18.1 to 21, incl.	4	100	400
21.1 to 24, incl.	6	100	600
24.1 to 27, incl.	8	100	800
27.1 to 30, incl.	12	100	1200
30.1 and over	16	100	1600

(*d*) *Yarn.*—Each test specimen shall consist of a section of the yarn approximately 0.75 in. in length. The twist shall be carefully removed and the fibers separated without loss. Test specimens from a single stretch of yarn shall be taken at least 10 in. apart. The number of test specimens and the number of measurements for the fineness range of the sample shall be in accordance with the requirements specified in Table I.

(*e*) *Fabrics.*—Each different yarn component of the fabric shall be tested in accordance with Paragraph (*d*).

Section 6.—Change to read as follows by the omission of the words in brackets:

"The fineness of the wool shall be calculated in terms of the arithmetic mean width in microns [of at least 200 fibers] and by the standard deviation or other methods of representing dispersion."

Section 7.—Add a note to read as follows: "NOTE.—The cross-section method is applicable only to white fibers."

Section 8.—Add a new Paragraph (*c*) to read as follows: "(*c*) For the cross-sectional examination of yarns, short lengths shall be inserted in the fiber slot, after the twist has been removed so as to facilitate insertion."

Standard Methods of Testing and Tolerances for Woven Glass Fabrics (D 579 – 43):

Section 10 (*a*).—Change the last sentence to read as follows by omission of the words in brackets: "In case of dispute, Method [A or] C shall be used."

Section 11.—Change Paragraph (*a*) to read as follows by the addition of the italicized words and the omission of the words in brackets: "The breaking strength of the fabric shall be determined on a [testing machine] ***pendulum type tester*** conforming to the Standard Specifications for Textile Testing Machines (A.S.T.M. Designation: D 76). [If a pendulum type of machine is used] The speed of the pulling clamp shall be 12 ± ½ in. per min."

Change Paragraph (*b*) by adding the following as the first sentence: "Tests shall be made by the raveled-strip method in accordance with Section 11 of the Standard General Methods of Testing Woven Textile Fabrics (A.S.T.M. Designation: D 39).

Section 12.—Change the second sentence to read as follows by the addition of the italicized words and figures and the omission of those in brackets: "The specimens shall be placed in a ventilated oven and heated for 1 hr. at a temperature of [425 to 500 C. (797 to 932 F.)] *500 ± 20 C. (932 ± 36 F.).*"

Standard Methods of Testing and Tolerances for Woven Glass Tapes (D 580 – 43):

Section 11 (*a*).—Change the last sentence to read as follows by omission of the words in brackets: "In case of dispute, Method [A or] C shall be used."

Section 15.—Make the same change in Paragraph (*a*) as is recommended above in Section 11 (*a*) of Methods D 579.

Standard Methods of Testing and Tolerances for Woven Glass Tubular Sleeving and Braids (D 581 – 43):

Section 12.—Make the same change in this section as is recommended above in Section 12 of Methods D 579.

Standard Specifications and Methods of Test for Asbestos Roving for Electrical Purposes (D 375 – 42):

Section 3 (*a*).—Revise the table for yards per pound requirements by adding a column for permissible variations for single tests and data for 16 and 18 cut rovings, and changing the column headings to read as follows:

Cut Designation	Nominal Yardage per Pound	Permissible Variations in Yards per Pound, Average of 10 Tests	Permissible Variations in Yards per Pound, Single Tests
5	500	450 to 549	400 to 599
6	600	550 to 649	500 to 699
7	700	650 to 749	600 to 799
8	800	750 to 849	700 to 899
9	900	850 to 949	800 to 999
10	1000	950 to 1049	900 to 1099
12	1200	1150 to 1249	1100 to 1299
14	1400	1300 to 1499	1200 to 1599
16	1600	1500 to 1699	1400 to 1799
18	1800	1700 to 1899	1600 to 1999

Section 4 (*a*).—Change the table of grades by adding a commercial grade and deleting grades AA, AAA, and AAAA, and appending a note as follows:

Grade	Asbestos Content
Commercial Grade	75 to 80 per cent, excl.
Underwriters' Grade	80 to 85 per cent, excl.
Grade A	85 to 90 per cent, excl.

NOTE.—The 16 and 18 cut rovings are available only in Commercial and Underwriters' grades; all other cuts are available in all three grades.

Section 6.—Delete this section and substitute the following:

6. *Sampling.*—(*a*) Each shipment shall be divided into lots of from 800 to 1000 lb. From each lot or fraction thereof, six cones, tubes, or cheeses of roving shall be taken at random and the tests prescribed shall be made on specimens removed from each package selected.

(*b*) If the tests from any lot fail to fall within the specified limits, a second set of samples shall be taken from another part of the lot and tested as before. The results of the two groups of tests shall be averaged to obtain the result for the lot.

(*c*) If the average values determined in accordance with Paragraph (*b*) fail to fall within the specified limits, the previous test results shall be discarded and a third set of samples shall be taken by selecting at random six cones, tubes, or cheeses from each 150 to 200-lb. unit of the material. The average results of tests on these six packages shall be considered the average of the particular unit tested, and each unit shall be accepted or rejected on this basis.

Section 8 (*a*).—Change to read as follows:

8. (*a*) *Number of Tests.*—Ten determinations of the number of yards per pound shall be made on each set of six packages selected. Individual test results and the average value of the ten tests shall fall within the respective permissible variations prescribed in the table given in Section 3 (*a*).

Change the last sentence of Paragraph (*b*) to read as follows by the addition of the italicized words and the formula: "The 24 yd. shall be weighed to the nearest 0.1 g. and the number of yards per pound calculated *from the following formula:*

$$Y = \frac{453.6 \times 24}{W}$$

where:

Y = yards per pound, and
W = weight of 24 yd. in grams."

Section 9.—Change the first sentence to read as follows: "Two specimens, weighing not less than 5 g. each shall be taken from each lot or unit sampled and dried to constant weight in an oven at 105 to 110 C. (220 to 230 F.), and the weights of the dried specimens recorded."

Change the last sentence to read as follows by the addition of the italicized words: "The average of the *two* determinations *made on the specimens from a given lot or unit* shall be the asbestos content *of that lot or unit.*"

TENTATIVE REVISIONS OF STANDARDS

Standard Methods of Testing and Tolerances for Tire Cord, Woven and on Cones (D 179 – 42):

New Section 14.—Add the following as a new Section 14 on the determination of yards per pound, renumbering the subsequent sections accordingly:

14. *Yards Per Pound.*—The yards per pound of cord on cones or spools shall be determined by reeling and weighing skeins of known yardage.

(*a*) *Test Condition.*—The reeling and weighing of skeins shall be made under standard conditions as defined in Section 2 of the Standard Methods D 39. The cones or spools shall have been previously conditioned in the standard atmosphere for at least 4 hr.

(*b*) *Preparation of Skeins.*—Skeins of at least 12 yd. in length shall be accurately reeled on a suitable reel at an approximate speed of 3 yd. per sec. Tension shall be applied to the cord by making two full wraps of the cord around the pigtail guide. In reeling from cones, the cone shall be placed below the reel with the center of the cone directly under the pigtail guide. In reeling from spools, the spool shall be placed on a horizontal spindle and so positioned that the horizontal center of the spool is directly under the pigtail guide.

(*c*) *Number of Tests.*—The number of tests shall be determined in accordance with Section 12.

(*d*) *Weighing.*—Each skein shall be weighed to the nearest 0.1 grain.

(*e*) *Moisture Regain.*—The actual moisture regain present in the cord shall be determined in accordance with Section 4 of the Tentative Methods of Quantitative Analysis of Textiles (A.S.T.M. Designation: D 629).

(*f*) *Calculations.*—The yards per pound shall be calculated and corrected to specified moisture regain from the following formulas:

$$Y = \frac{L \times 7000}{W}$$

$$Y_c = \frac{Y(100 + A)}{100 + R}$$

where:

Y = measured yards per pound,
L = length of skein in yards,
W = weight of skein in grains,
Y_c = yards per pound, corrected to specified percentage moisture regain,
A = actual percentage moisture regain in cord, and
R = specified percentage moisture regain.

New Sections.—Add the following as new Sections 23, 24, and 25 on verification of recorded elongation:

VERIFICATION OF ELONGATION RECORDED BY PENDULUM TYPE CORD TESTING MACHINES

22. *Verification of Specimen Length: (a) Distance Between Clamps.*—The distance between the nips of the clamps along the line of the cord shall be 10 ± $\frac{1}{32}$ in.

(*b*) *Procedure.*—The dial pointer shall be set at zero load and the clamp connected with the pulling mechanism returned to its normal position of rest after the completion of the test. A cord shall be placed between folded pieces of carbon paper in the clamps in such a manner that the carbon side of the paper faces the front and back of the cord and the lower clamp tightened. The free end of the cord emerging from the upper clamp shall be placed under a tension of 4 oz. and this clamp also tightened. Using a template inscribed with two marks exactly 4 in. apart, a distance of exactly 4 in. shall be marked off with a sharp pencil on the cord while it is still gripped in the clamps. The cord shall then be removed from the clamps, placed under such tension that the distance between the pencil marks remains exactly 4 in. and the distance between the carbon marks on the cord shall be measured with a steel rule (Note 1). If the distance between the carbon marks falls outside of the tolerance prescribed in Paragraph (*a*), the distance shall be adjusted between the clamps and the length of the specimen rechecked until the proper distance is secured (Note 2).

(*c*) *Gage Rod.*—A gage rod shall be prepared of such length that it fits exactly between the butts of the clamps (or between some other gage marks) when the cord length meets the specified tolerance. This rod shall be used for subsequent checks on the pair of clamps for which it is prepared (Note 3).

NOTE 1.—If the clamps have spools which bear on the cord above the main block, disregard the spool marks and measure the length between the marks made by the blocks.

NOTE 2.—The length of the specimen measured in this way will fall within the specified tolerances for cords having an appreciable variation in thickness, but if abnormally heavy cords or very thin cords are to be tested the specimen length should be checked with the material of the type under test.

NOTE 3.—The gage rod is normally about 6 in. in length but may vary slightly from one pair of clamps to another. The suitability of a given rod must be determined for each pair of clamps used.

23. *Verification of Recorded Elongation.*—The upper clamp shall be adjusted so that the dial pointer indicates zero load and the pulling clamp returned to its normal position of rest after the completion of a test. A chart shall be placed in the holder and so adjusted in position that the pen rests at zero load and zero elongation (Note 1). The distance shall be measured between the butts of the clamps using a pair of calipers and a steel rule. A specimen having a high elongation (30 per cent), such as bare, soft-drawn copper wire, shall be placed in the clamps, and the tester operated by hand (or mechanically) until the pen indicates exactly 10 per cent elongation, then stopped and the distance measured between the butts of the clamps using a pair of calipers and a steel rule. This distance under the conditions outlined shall be equal to the original distance plus 1 in. This operation shall be repeated with elongations corresponding to 20 and 30 per cent (Note 2).

NOTE 1.—On machines having a specific location for the chart as determined by supports, the chart should be placed in its proper location and the pen adjusted to record zero load and zero elongation.

NOTE 2.—It is not essential to use elongations of exactly 10, 20, and 30 per cent as long as the proper increment is obtained, thus an indicated elongation of 14 per cent would be equivalent to an increment of 1.4 in.

24. *Causes of Improper Recording.*—Failure of the tester to record the proper elongation may be due to one or more of the causes given in the following Paragraphs (*a*) to (*g*) together with methods of checking. One or more of these possibilities may not apply to a particular type of tester.

(*a*) *Faulty Ruling of Charts.*—The rulings on the charts should be at right angles, or at a specified angle.

(*b*) *Faulty Cutting of Chart Sheets.*—The edges of the chart should be parallel and the sides should be at right angles to the top and bottom. The edges should be cut through a line printed outside the ruled area as a guide for this purpose. The presence of this cut line can be detected at the edge of a properly cut chart.

(*c*) *Failure of Chart, Pen, and Clamp to Start Moving at the Same Time.*—Poor coordination of movement is indicated by a changing error in the recorded elongation when calculated on a percentage basis.

(*d*) *Improper Geometry.*—A chart shall be inserted as directed in Section 23 and the pen set to record zero load and zero elongation. The tester shall be operated without any specimen in order to register increasing elongation at zero load. The line inscribed on the chart should be parallel with the line indicating variable elongation at zero load. Without altering the position of the chart in the holder, the pen shall be reset at zero load and zero elongation. The pendulum shall be loaded without permitting any elongation by clamping a "nonextensible" member, such as a strip of thin steel, in both the clamps. The machine shall be operated and the pen allowed to draw a line on the chart. This line should be parallel with the chart line indicating variable load and zero elongation. If the charts are correctly printed and the zero elongation and zero load lines drawn during the test do not parallel the chart lines, the geometry of the tester shall be adjusted until this result is obtained.

(*e*) *Improper Angle of Pen Carriage.*—A chart shall be placed in the tester and adjusted in its position so that the pen registers zero load and about 35 per cent elongation. Without any sample in the clamps, the pendulum shall be allowed to swing until the pointer indicates the maximum capacity of the chart. Under these conditions the end of the line traced by the pen should rest on the full load line and should make a specified angle with the base line. Any variation from the theoretical angle will produce a difference in the readings observed on the dial and on the chart unless the movement of the pen is also in error.

(*f*) *Improper Traverse Movement of the Pen.*—Improper traverse of the pen can be caused by a compacted cable or by a stretched cable on testers using this type of mechanism. It can also be caused by the use of different diameter pulleys on a single shaft; the ratio of the circumference of these pulleys may be in error.

(*g*) *Improper Magnification of Chart—or Pen Movement, or Both.*—Magnification of the movement of the chart where this is obtained by means of a movable pulley will not be in error providing the diameter of the cable is constant.

Standard Methods of Testing Wool Felt (D 461 – 40):

New Section 2.—Add a new Section 2 on definitions to read as follows, renumbering the subsequent sections accordingly:

2. *Definitions:* (*a*) *Hardness.*—That property by virtue of which the felt resists local pressure applied to its surface.

(*b*) *Density.*—The weight per unit volume of the felt under test as distinguished from the volume of the fiber.

(*c*) *Resilience.*—The property of a material by virtue of which the material is able to do work against restraining forces during return from a deformed state.

New Section.—Add a new Section 18 to read as follows:

AMOUNT OF ACID IN FELT (PYRIDINE EXTRACTION METHOD)

18. (*a*) *Sampling.*—A representative sample of approximately 12 to 15 g. of the felt shall be cut into ⅛ to ¼-in. squares and thoroughly mixed to insure uniformity.

(*b*) *Pyridine Solution.*—The pyridine solution shall be prepared by dissolving 10 ml. of pyridine (reagent grade) and 20 g. of sodium chloride (reagent grade) in one liter of distilled water.

(*c*) *Procedure.*—Approximately 2 g. of the material prepared in accordance with Paragraph (*a*) shall be accurately weighed and transferred to a dry (Note) 500-ml. Erlenmeyer flask, into which 100 ml. of pyridine solution shall be added. The contents shall be shaken well to wet thoroughly the felt, and allowed to steep for ¾ hr. with occasional agitation. The extract shall be decanted into a 400-ml. beaker, and the felt squeezed with a large diameter stirring rod to remove as much of the extract as possible. The felt shall then be washed by adding 75 ml. of pyridine solution to the flask and allowing it to stand for 10 min. with frequent agitation, then decanting and adding the wash solution to the original extract. The washing and decanting shall be repeated twice more with 75 ml. of pyridine solution. The total volume of solution, approximately 325 ml., shall be filtered through a

No. 1 filter paper to remove loose fibers. Then 3 or 5 drops of phenolphthalein (1 per cent) shall be added and the solution titrated to a faint pink end point with 0.05 *N* sodium hydroxide.

NOTE.—If colored felts become wet before the pyridine solution has been added, there may be some bleeding of the color.

(*d*) *Blank.*—A blank shall be run on an equal volume of the pyridine solution parallel with that on the extract to determine the volume of 0.05 *N* sodium hydroxide required for the reagents. The volume so determined shall be subtracted from that required for the extract.

(*e*) *Calculation.*—The milliequivalents of acid per gram of felt shall be calculated as follows:

$$A = \frac{(C - B)N}{W}$$

where:

A = milliequivalents of acid per gram of felt,
B = milliliters of sodium hydroxide for blank, required,
C = milliliters of sodium hydroxide for extract, required,
N = normality of sodium hydroxide solution, and
W = weight of test specimen (Paragraph (*c*)) in grams.

Standard Specifications for Textile Testing Machines (D 76 - 42):

Section 2.—Change from its present form to read as follows:

2. *Classes of Machines.*—Tensile testing machines for use on textile materials shall conform to the requirements of Sections 3, 4, 5, and 6, and may be generally classed as operating either on the constant-rate-of-traverse or constant-rate-of-load principles.

NOTE 1.—The pendulum testing machine is typical of the constant-rate-of-traverse class. One end of the specimen is held by a moving clamp operated at a constant speed while the other end is held by a clamp attached to a weighing mechanism incorporating a mechanical linkage and a pendulum. In the constant-rate-of-load class of machine, load is applied to the specimen at a fixed rate of increase, in one construction through a weighted carriage operating on an inclinable plane.

NOTE 2.—Both mathematical analysis and tests indicate the possibility of significant inertia errors in testing machines whose weighing mechanisms are massive, especially if such machines are used on materials with low damping capacities or are operated at high speeds. Caution should therefore be used in testing other than conventional materials, in operating at high speeds, and in testing specimens which break near the lower end of the range, on such machines.

Section 3.—Change from its present form to read as follows:

3. *Machine Operation.*—(*a*) Machines in the constant-rate-of-traverse class shall preferably be power driven, and shall be so operated that the pulling clamp has a uniform speed of 12 ± ½ in. per min., unless otherwise specified.

(*b*) Machines in the constant-rate-of-load class shall preferably be power driven, and shall be operated in such a manner that those machines having a capacity up to 1000 g. shall apply the full machine load in 60 sec., and machines having a capacity above 1000 g. shall apply the full machine load in 20 sec., unless otherwise specified.

NOTE.—Certain machines in the constant-rate-of-load class have been fitted either with a variable speed drive or with a variable weighted carriage in order to permit loading at a given rate per unit specimen size.

Section 4.—Delete this section and substitute the following:

4. *Verification.*—This section provides a general basis for the verification of tension testing machines for textiles, and no attempt is made to give detailed instructions applicable to any particular case (Note). The verification should be supervised by a person competent to exercise scientific judgment in matters not covered herein.

NOTE.—Detailed instructions for certain particular cases are being prepared.

(*a*) Tension testing machines for textiles shall be verified periodically, and the requirements of the Standard Methods of Verification of Testing Machines (A.S.T.M. Designation: E 4) shall be followed except as otherwise provided in the following Paragraphs (*b*), (*c*), and (*d*):

(*b*) The machine shall be verified in the condition under which it is to be used, with all attachments and recording mechanisms in operation if they are to be used in actual testing, except that any pawls or other detent in the weighing mechanism shall be rendered inoperative. In verification the test load shall be applied statically, with the pawls or other detent held inoperative, and the effect of friction shall be eliminated by gently oscillating the weighing mechanism or by tapping the machine to insure that the applied test load is in equilibrium with the force of the weighing mechanism.

(*c*) An examination shall be made to detect any friction or slack in the weighing, indicating, or recording mechanisms, and the action of such defects shall be estimated in terms of the units in which the machine is calibrated. The possible errors in load indication of the machine due to such friction or slack or to the least count (see Note, Section 6 (*a*)) of any detent mechanism, or due to combinations of these causes, shall not exceed the tolerance in load indication (Section 5). If any errors so found exceed this tolerance, or if they appear to indicate significant defects in the mechanism, the machine shall not be used until it has been overhauled, any defects corrected, and the errors reduced to come within the tolerance.

(*d*) If the construction of the machine is such that other than vertical test loads must be applied, suitable apparatus may be devised subject to the general requirements for accuracy of calibration devices prescribed in Standard Specifications E 4. If cords and pulleys are used the construction shall be such that errors due to axle friction, pulley eccentricities, cord friction, and indeterminateness of cord center line shall be within the required limits of Standard Specifications E 4. If an elastic calibration device is used, due account shall be taken of possible variations in its readings due to inclined position.

New Sections.—Add a new Section 5 on tolerance in load indication, and a new Section 6 on working range and capacity, renumbering the subsequent sections accordingly:

5. *Tolerance, Load Indication.*—The tolerance in load indication shall not be more than plus or minus 1 per cent.

6. *Working Range and Capacity.*—(*a*) The working range or ranges of a tension testing machine shall be the range or ranges which have been shown by verification to have errors not exceeding the tolerance, but shall not extend below a load which is 50 times the least count (Note) of the testing machine or 50 times the machine sensitivity, whichever is the greater.

NOTE.—The "least count" is the smallest change in indication which can customarily be determined and reported. In machines with close graduations, it may be the value of a graduation interval; with open graduations, or with magnifiers, for reading, it may be an estimated fraction, rarely as fine as one tenth, of a graduated interval; and with verniers it is customarily the difference between the scale and vernier graduations measured in terms of scale units. If the indicating mechanism includes a stepped detent, the detent action may determine the least count.

(*b*) In making a test a machine shall be selected whose working range includes the probable breaking load of the specimen.

NOTE.—These restrictions are intended particularly to prevent the testing of weak specimens on heavy machines, where the results may be affected by limitations due to machine friction, inertia, scale graduations, and other factors.

REPORT OF COMMITTEE D-16
ON
INDUSTRIAL AROMATIC HYDROCARBONS

The organization of a standing Committee on Industrial Aromatic Hydrocarbons was authorized by the Executive Committee of the Society on June 27, 1943, after it had considered suggestions from a number of sources that an A.S.T.M. technical committee could contribute much in this field through the development of standard methods of test, definitions, and specifications for these materials. The preliminary scope of activities of the new committee is as follows:

Scope.—Nomenclature, methods of test, and specifications for industrial aromatic hydrocarbons and related products boiling below 400 F. for other than fuel purposes.

The organization meeting of the committee was held in New York, N. Y., on October 26, 1943, at which time the following temporary officers were elected:

Temporary Chairman, J. M. Weiss.

Temporary Vice-Chairman, C. A. Lunn.

Temporary Secretary, R. P. Anderson.

The following subcommittees have been organized with officers as indicated:

Subcommittee I on Methods of Test for Crude Aromatic Products (C. A. Lunn, chairman; D. F. Gould, vice-chairman):

This subcommittee is cooperating with Subcommittee II on Methods of Test for Refined Aromatic Products in developing methods of sampling. The subcommittee is investigating methods for determining aromatic hydrocarbons in light oil.

Subcommittee II on Methods of Test for Refined Aromatic Products (V. J. Altieri, chairman; E. T. Scafe, vice-chairman):

This subcommittee has been active in its examination of various methods of test that may be acceptable for publication as tentative. These include the following tests: acid wash, acidity, color, odor, copper corrosion, distillation, nonvolatile matter, paraffins, solidifying point of benzene, and specific gravity. The subcommittee is acting jointly with Subcommittee I in developing methods of sampling.

Subcommittee III on Specifications for Aromatic Chemicals (J. N. Wickert, chairman; Wesley Minnis, vice-chairman):

This subcommittee has studied the requirements for nitration grade benzene, toluene, and xylene and for industrial pure benzene and toluene; and has prepared five proposed specifications for consideration by the committee.

Subcommittee IV on Specifications for Aromatic Solvents (R. F. Ruthruff, chairman; F. J. Van Natta, vice-chairman):

This subcommittee has studied the requirements for various solvents and has prepared seven specifications, based on past practice in the coal products industry, for consideration by the committee. These cover 10-deg. xylene, refined solvent naphtha, crude light solvent naphtha, crude heavy solvent naphtha, industrial 90 benzene, industrial pure toluene, and industrial xylene. The last three products are now covered by A.S.T.M. Standard Specifications for Industrial 90 per cent Benzene (D 361 – 36), for Industrial Pure Toluene (Toluol) (D 362 – 36), and for Industrial Xylene (Xylol) or Solvent Naphtha (D 364 – 36), respectively, but the subcommittee is considering additional requirements for these products.

Subcommittee V on Nomenclature (D. F. Gould, chairman; J. Bennett Hill, vice-chairman):

This subcommittee is submitting the following recommendations for consideration by the other subcommittees:

(*1*) That the "ene" ending for aromatic hydrocarbons be used in place of the "ol" ending with a footnote to read, "formerly known as '. . . . ol'."

(*2*) That the material known as "industrial 90 per cent benzene" be referred to as "industrial 90 benzene" as the former term may be misunderstood to indicate the actual benzene content of the material.

It is expected that the various methods of test and specifications being developed by the several subcommittees will soon be available for comment and criticism.

In effecting organization, Special Subcommittees on Scope and By-Laws were appointed under the chairmanship of R. P. Anderson and W. H. Fulweiler, respectively.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, J. M. Weiss.
Vice-Chairman, V. J. Altieri.
Secretary, R. P. Anderson.

This report has been submitted to letter ballot of the committee which consists of 33 voting members; 26 members returned their ballots, of whom 23 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the committee,

J. M. WEISS,
Temporary Chairman.

R. P. ANDERSON,
Temporary Secretary.

REPORT OF COMMITTEE D-17

ON

NAVAL STORES

Committee D-17 on Naval Stores has held two meetings during the year: in Pittsburgh, Pa. on June 29, 1943, in connection with the Annual Meeting of the Society, and in Cincinnati, Ohio, on February 29, 1944, in connection with the Spring Group Meetings.

The establishment and personnel of an Advisory Committee to handle additions to the membership of the committee and other matters requiring group attention between meetings were approved at the Pittsburgh meeting.

The reorganization and broadening of the scope of the work of Committee D-17 to include turpentines, rosins, pine oleoresins, pine oils, rosin oils, wood tars and wood pitches has resulted in increased interest and an expansion of the membership of the committee. Seventeen new members or company representatives have been added to the personnel.

In order to expedite the handling of new standards or the revision of existing standards for turpentine and similar terpene paint thinners, which are under the jurisdiction of Subcommittee V on Volatile Solvents for Organic Protective Coatings of Committee D-1 on Paint, Varnish, Lacquer and Related Products, an informal arrangement was made with the D-1 subcommittee whereby the initial steps on any such standards will be handled by Committee D-17 through its Subcommittee VII. The scope and title of this subcommittee has been broadened to cover Terpene Hydrocarbons and Pine Oil. Further information with respect to the work of this subcommittee appears later in this report.

It was recommended at the Pittsburgh meeting that a set of by-laws be prepared for the guidance of the officers, subcommittee chairmen, and members in the handling of committee affairs. This matter has been referred to the Advisory Committee.

I. NEW TENTATIVE STANDARDS

The committee recommends the following for publication as new tentative standards:

Definitions of Terms Relating to Tall Oil,
Methods of Testing Tall Oil,
Methods of Sampling and Testing Pine Oil, and
Methods of Sampling and Testing Dipentene.

These recommendations have been submitted to letter ballot of the committee which consists of 34 members. On the first three items 23 members returned their ballots, of whom 22 have voted affirmatively, 0 negatively, and 1 member marked his ballot "not voting." On the last item the vote was 21 affirmative, 0 negative and 2 ballots marked "not voting."

REVISION OF TENTATIVE STANDARD

In view of several negative votes against the adoption as standard of the Tentative Methods of Sampling and Grading Rosin (D 509 – 38 T), it was decided to rewrite the methods and to eliminate the references to procedures used in sampling rosin at the producing plants and primary inspection points, such as the southern concentration and storage yards. The special subcommittee named for this assignment, consisting of V. E. Grotlisch and W. C. Smith, has completed the revision and the methods as revised are recommended for publication as tentative as appended hereto.[1]

This recommendation has been submitted to letter ballot of the committee which consists of 34 members; 25 members returned their ballots, of whom 19 have voted affirmatively, 0 negatively, and 6 members returned their ballots marked "not voting."

The revised Methods of Sampling and Testing Turpentine (D 233 – 36) referred to under the report of Subcommittee VII have been approved by letter ballot in Committee D-17 which consists of 34 members; 23 members returned their ballots, of whom 22 have voted affirmatively, 0 negatively, and 1 member marked his ballot "not voting."

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Softening Point of Rosin (C. E. Kinney, chairman) has been collecting information on the practicability of substituting an air bath in place of the water or glycerin bath now specified in the Tentative Method of Test for Softening Point (Ball and Shouldered Ring Apparatus) (E 28 – 42 T), in view of the variation in the results obtained on rosins having softening points in the change-over range around 80 C. (176 F.) depending upon whether water or glycerin is used as the heat-conducting mediun. Preliminary study is being made of other published or proposed methods which appear applicable in determining the softening point of rosin, in order to find a method which will be more rapid and better adapted to routine plant control work. Members of the committee and any others interested in the subject are invited to submit to the chairman of the subcommittee any suggestions or ideas on possible softening point methods adapted to rosin or similar resinous materials which would lend themselves to standardization, and which have the following desirable features: simple design and low cost of construction, rapid procedure, good reproducibility (within 1 C.), and adaptability to a wide range of softening points.

Subcommittee II on Crystallization of Rosin (E. V. Romaine, chairman) has, through its chairman, been conducting some preliminary studies at a southern producing plant to evaluate the factors on which crystallization tendency depends, and from the data so obtained expects to be able to outline a procedure which will give more reproducible results than have been obtained from previous methods submitted for collaborative tests.

Subcommittee IV on Acid and Saponification Number and Unsaponifiable Matter in Rosin (C. C. Zeigler, chairman) has received a series of rosin samples for collaborative study of several modifications of the Standard Methods of Test for Acid Number (D 465 – 42) and for Saponification Number (D 464 – 42) of rosin and also for use in a study of an electrometric titration procedure in order to develop methods which will be more suitable for analysis of dark-colored rosins. A Proposed Method of Test for Unsaponifiable Matter in Rosin, which was suggested several years ago by I. E. Knapp, a member of the committee, is also being studied for the purpose of standardization and is published as information in the Appendix.

Subcommittee V on Tall Oil (A.

---

[1] These methods were accepted as tentative by the Society and appear in the 1944 Book of A.S.T.M. Standards, Parts II and III.

Pollak, chairman) has completed its organization. The chairman has assembled definitions of terms and methods of test applicable to tall oil (sometimes erroneously described as "liquid rosin") based on the experience gained in his laboratory. These methods and definitions are recommended for publication as tentative as mentioned earlier in this report.

Subcommittee VI on Pine Tar and Tar Oil (J. P. Bain, chairman) has also completed its organization. Study is being made of the relationship between the several properties and test procedures on which pine tars have been classified and evaluated. The members have been furnished with some preliminary data along this line, and from the recommendations made, methods of test have been drawn up for further study, to include viscosity, specific gravity, distillation, moisture, evaporation loss, and ash. Since tars contain flocculent suspended carbonaceous matter, which affects the viscosity but not so much the density of the tar, viscosity determinations by means of the Stormer viscosimeter, in terms of absolute viscosity units (centipoises) will be included in the proposed methods of test, for comparison with observations made with other types of viscosimeters based on time-of-outflow of a specified volume of material.

Subcommittee VII, on Terpene Hydrocarbons and Pine Oil (I. E. Knapp, chairman) has drafted and approved a proposed tentative revision of the Standard Methods of Sampling and Testing Turpentine (D 233 – 36) and submitted it to Subcommittee V of Committee D-1 on Paint, Varnish, Lacquer, and Related Products. Pinene has been included in the scope of the methods and references have been added to other A.S.T.M. standard methods, in so far as they are applicable to testing turpentine, in place of detailed directions. Another proposed change involves the definition of a standard for a color grade of turpentine known in the trade as Waterwhite turpentine. Several alternative test procedures for use in making the color test have also been proposed, one of which is based on the color of potassium platinic chloride, the other referring to the Saybolt chromometer method (D 156 – 38). A simplified temperature correction table has been prepared for adjusting temperature readings in the distillation test for variations in barometric pressure, with corrections applicable also to aneroid barometer readings.

Proposed Methods of Sampling and Testing Dipentene and Pine Oil are submitted herewith for publication as tentative as referred to earlier in this report.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, V. E. Grotlisch.
Vice-Chairman, E. V. Romaine.
Secretary, W. A. Kirklin.
Members-at-Large of Advisory Committee: J. L. Boyer, R. P. Chapman, R. E. Pflaumer, A. Pollak.

This report has been submitted to letter ballot of the committee which consists of 34 voting members; 28 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

V. E. GROTLISCH,
Chairman.

W. A. KIRKLIN,
Secretary.

APPENDIX

PROPOSED METHOD OF TEST FOR UNSAPONIFIABLE MATTER IN ROSIN[1,2]

This is a proposed method and is published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 260 S. Broad St., Philadelphia 2, Pa.

1. *Scope.*—This method of test is intended for determining the percentage of material in rosin, other than insoluble dirt or other similar visible foreign matter, which does not yield a water-soluble soap when the material is saponified with sodium hydroxide or similar caustic alkali.

2. *Apparatus.*—The apparatus in which the unsaponifiable matter is extracted from the soap solution, shown in Figs. 1 and 2, shall consist of the following:

(*a*) *Erlenmeyer Flask.*—A standard flat-bottom Erlenmeyer flask of 250-ml. capacity with a ground-glass joint of standard 24/40 taper.

(*b*) *Extractor Tube.*—A special extractor tube,[3] shown in Fig. 1, 42 cm. in length, with a side tube placed 22 cm. above the bottom of the tube. The bottom of the side tube and the top of the extractor tube shall be fitted with ground-glass joints of standard 24/40 taper.

(*c*) *Conductor Tube.*—A conductor tube,[3] also shown in Fig. 1, for conducting condensed solvent to bottom of extractor tube, having a length of 35 cm., with the top flared to funnel shape and the bottom blown to a bulb, 12 to 14 mm. in diameter, and perforated with three 1-mm. holes.

(*d*) *Reflux Condenser.*—A reflux, water-tube condenser having a water jacket 40 cm. in length.

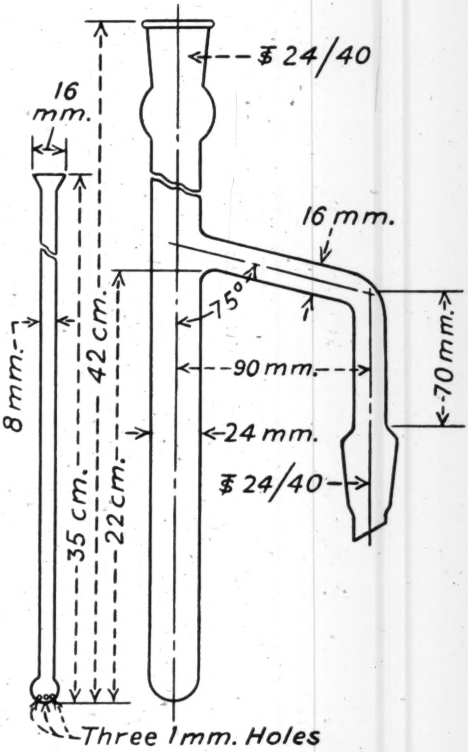


FIG. 1.—Extractor Tube.

3. *Procedure:* (*a*) *Saponification.*—The preliminary saponification to convert the saponifiable rosin acids and other similar constituents into water-soluble soap shall be conducted as follows: Dissolve 30.00 g. of rosin in 200 ml. of anhydrous alcohol in a 500-ml. round-bottomed flask, with gentle heating, and to the slightly cooled solution add 6.0 ml. of 50 per cent sodium hydroxide

---

[1] This proposed method is under the jurisdiction of the A.S.T.M. Committee D-17 on Naval Stores. Published as information, June, 1945.

[2] For information concerning the experimental work on which this method of test is based see I. E. Knapp, "Determination of Unsaponifiable Matter in Rosin," *Industrial and Engineering Chemistry*, Analytical edition, Vol. 9, p. 315 (1937).

[3] This apparatus is available from several laboratory glassware makers.

solution (sp. gr. 1.52). Boil gently under a reflux condenser for 1.5 hr. and then add 150 ml. of water together with an ebullition tube. Set the flask in an oil or glycerol bath and connect it to a condenser. Hold the temperature in the bath at 120 to 130 C. until the total volume of the distillate amounts to 210 ml. Transfer the rosin soap solution quantitatively to a 250-ml. volumetric flask, cool, and dilute to the mark with distilled water.

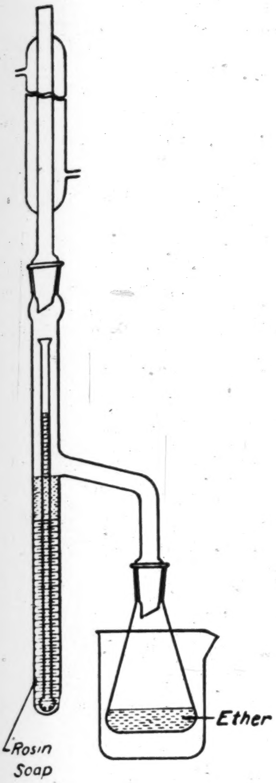


FIG. 2.—Complete Extraction Apparatus.

(*b*) *Extraction of Unsaponifiable Matter.*—To obtain the unsaponifiable matter, pipette a 50-ml. aliquot into the extractor tube. Place 100 ml. of ethyl ether in the Erlenmeyer flask, connect the flask to the extractor, and set in a water bath maintained at 50 to 55 C. by an electric hot plate. Continue the extraction for 6 hr. with the reflux rate approximately 3 drops per second. Pour the ether solution into a 500-ml. Squibb separatory funnel and rinse out the flask with two 15-ml. portions of fresh ether. Shake thoroughly with 50 ml. of 1 per cent sodium hydroxide solution. Draw off the aqueous layer into a second separatory funnel and to it add 30 ml. of fresh ether; shake thoroughly and discard the aqueous layer. Run the ether back into the first separatory funnel and wash the combined ether solutions three times with 50-ml. portions of distilled water. Run the washed ether solution into a carefully tared 250-ml. flask, rinsing the separatory funnel with 15 ml. of fresh ether. Immerse the flask in a water bath and distill off the ether. Then raise the temperature of the water to 67 to 70 C. and maintain a vacuum of 20 to 25 mm. of mercury for 30 min. Remove the flask, cool, and weigh. The material recovered is the "net washed extract." Dissolve it in about 40 ml. of neutral alcohol and titrate with standard alcoholic potassium hydroxide (preferably 0.1 *N*) to a phenolphthalein end point.

4. *Calculation.*—Calculate the percentage of unsaponifiable matter in the rosin as follows:

$$E = \frac{\text{wt. of net washed extract}}{\text{wt. of rosin in aliquot (6 g.)}} \times 100.$$

$$A = \frac{\text{ml. of standard alkali} \times N \times 30.2}{\text{wt. of rosin in aliquot}}$$

$$\text{Unsaponifiable matter, per cent} = E - A$$

where:

E = percentage of extract,
A = percentage of rosin acids, and
N = normality of NaOH.

REPORT OF COMMITTEE D-18
ON
SOILS FOR ENGINEERING PURPOSES

Committee D-18 on Soils for Engineering Purposes held one meeting during the year, on June 28, 1943, in Pittsburgh, Pa.

Subsequent to the 1943 Annual Meeting Committee D-18 presented to the Society through Committee E-10 on Standards a proposed tentative revision of the Standard Method of Mechanical Analysis of Soils (D 422 – 39). This tentative revision was accepted[1] by Committee E-10 on August 30, 1943, and appears in the 1944 Book of A.S.T.M. Standards, Part II, p. 616.

It was with deepest regret that Committee D-18 learned of the death of Paul Rapp on August 6, 1943. The committee will continue to feel the loss of Mr. Rapp's tireless efforts as Chairman of Subcommittee IV and his participation in the Symposium on Soil Testing Methods.

The Symposium Committee headed by F. C. Lang, University of Minnesota, in cooperation with other committee members and the officers developed a compilation of Procedures for Testing Soils[2] which, through the intensive work of Committee D-18, has now been issued by A.S.T.M. preliminary to a discussion or symposium on soil testing to be held at one of the future meetings of the Society. The book is arranged in five sections with standard tests, if any, covered first under each section, followed by suggested methods. The five parts are as follows: Part I, Indicator Tests on Soils; Part II, Compaction and Consolidation Tests on Soils; Part III, Strength Tests on Soils; Part IV, Tests for Soil Cement; and Part V, Tests for Soil-Bituminous Mixtures. Committee D-18 has carried out a great deal of work in this field, has held numerous discussions, and is desirous of eliciting comments particularly on the suggested procedures.

ADOPTION OF TENTATIVE STANDARDS AS STANDARD

Committee D-18 recommends jointly with Committee D-4 on Road and Paving Materials that the following three tentative methods, under the joint jurisdiction of the two committees, be approved for reference to letter ballot of the Society for adoption as standard, with revisions in Method D 558 as referred to later in the report of the Joint Subcommittee of Committees D-4 and D-18 on Tests and Specifications for Stabilized Soils:

Tentative Methods of:[3]

Test for Moisture-Density Relations of Soil-Cement Mixtures (D 558 – 40 T), with revisions,

Wetting-and-Drying Test of Compacted Soil-Cement Mixtures (D 559 – 40 T), and

Freezing-and-Thawing Test of Compacted Soil-Cement Mixtures (D 560 – 40 T).

These recommendations have been submitted to letter ballot of the committee which consists of 76 voting members, with the results shown in Table I.

---

[1] In submitting this recommendation to Committee E-10 on Standards, Committee D-18 reported results of the letter ballot vote as follows: Of a total membership of 68, 44 members returned their ballots, of whom 43 voted affirmatively, 0 negatively, and 1 member marked his ballot "not voting."

[2] Issued as a separate publication, September, 1944.

[3] 1942 Book of A.S.T.M. Standards, Part II.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee III on Methods of Sampling Soils (C. W. Allen, acting chairman) has under consideration the Tentative Methods of Surveying and Sampling Soils for Highway Subgrades (D 420 – 42 T) looking toward their adoption as standard. During the coming year, the subcommittee is planning to discuss the application of aerial photography and resistivity methods in soil surveys.

Subcommittee IV on Methods of Testing the Physical Characteristics of Soils (Harold Allen, chairman) has not made the progress expected since its work had been interrupted by the death of Mr. Paul Rapp, who had served as chairman of the subcommittee since 1940.

TABLE I.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
ADOPTION OF TENTATIVE STANDARDS AS STANDARD			
Test for Moisture-Density Relations of Soil-Cement Mixtures (D 558 – 40 T), as revised	49	0	9
Wetting-and-Drying Test of Compacted Soil-Cement Mixtures (D 559 – 40 T)	43	1	13
Freezing-and-Thawing Test of Compacted Soil-Cement Mixtures (D 560 – 40 T)	42	1	14

The subcommittee hopes to clear up the several questions raised by Committee E-10 on Standards in failing to approve the proposed Tentative Methods of Test for Specific Gravity of Soil in February, 1943. It likewise plans to give consideration to the development of standard methods of determining the moisture content of soils in place. The topic of "densities in place" has also been referred to this subcommittee.

Subcommittee X on Methods of Testing for Bearing Capacity of Piles (Load Tests) (A. E. Cummings, chairman) has prepared draft methods for pile load tests which are now under consideration.

Joint Subcommittee of Committees D-4 and D-18 on Tests and Specifications for Stabilized Soils (H. F. Clemmer, chairman) which was organized a year ago has held two meetings during the year and has made definite progress. As indicated earlier in this report, the subcommittee has recommended that the Tentative Method of Wetting-and-Drying Test of Compacted Soil-Cement Mixtures (D 559 – 40 T) and the Tentative Method of Freezing-and-Thawing Test of Compacted Soil-Cement Mixtures (D 560 – 40 T) be adopted as standard without change and that the Tentative Method of Test for Moisture-Density Relations of Soil-Cement Mixtures (D 558 – 40 T) be adopted as standard, revised as follows:

Section 3.—Add a new sentence after the second sentence of Paragraph (*b*) to read as follows: "A quantity of water sufficient to produce slight cohesion shall then be thoroughly mixed with the soil-cement sample to permit ready compaction."

Change the end of the present third sentence to read as follows by the addition of the italicized words and the omission of those in brackets:

> each layer being compacted by 25 blows of the rammer dropping free from a height of 12 in. above the elevation of [each finally compacted layer] *the soil when a sleeve-type rammer is used or 12 in. above the approximate elevation of each finally compacted layer when a stationary mounted type rammer is used.*

At the end of the present fourth sentence, change the phrase "or of equivalent rigidity" to read "or its equivalent."

In order to have the procedure conform in all details with the above changes, in Paragraph (*c*) change "air-dry soil-cement mixture" to read "initial soil-cement mixture."

Section 5.—In order that "optimum moisture" and "maximum-density" be determined for soils producing irregular moisture-density curves that are not of the parabolic type, add the following new Paragraph (*d*) to this section:

> (*d*) When the curve resulting from connecting plotted points does not produce a parabolic-type curve with a definite peak, the "optimum moisture" and "maximum density" for such mixtures shall be determined from the results of additional tests conducted in conformance with the Standard Method of Wetting-and-Drying Test of Compacted Soil-Cement Mixtures (A.S.T.M. Designation: D 559) and the Standard Method of Freezing-and-Thawing Test of Compacted Soil-Cement Mixtures (A.S.T.M. Designation: D 560) on compacted soil-cement specimens. These specimens shall be molded with moisture contents approximately equal to the plastic limit of the soil and 1, 2, and 3 per cent above and below this governing moisture content. The densities of these specimens shall be those obtained with the prescribed moisture contents in the moisture-density test for the mixture. The cement content of these specimens shall be such that the soil-cement losses on the specimen giving the best results in these tests shall not exceed 10 per cent of the dry weight of the specimen. The moisture content and density corresponding to the specimen giving the best results shall be used as the "optimum moisture content" and "maximum density" of soil-cement mixtures which do not produce a parabolic-type curve.

This subcommittee is planning to submit a proposed Method of Test for Determining Cement Content of Soil-Cement Mixtures to Committee D-18 and Committee D-4 on Road and Paving Materials for consideration looking toward their submittal to Committee E-10 on Standards for publication as tentative.[4]

A special subgroup on Correlation of Results of Various Tests with CBR Tests, under the chairmanship of E. W. Klinger, has been particularly active and has presented several progress reports. It is expected that this subgroup may present a final report previous to the fall meeting of the subcommittee.

The subcommittee has under consideration methods of test for soils treated with plastic binders, waterproofers, etc., as well as a Proposed Method of Test for Water Absorption, Expansion, and Strength Characteristics of Soil-Bituminous Mixtures,[5] proposed by the Bituminous Producers Cooperative Research Committee, which was recently referred to it.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, C. A. Hogentogler
Vice-Chairman, E. J. Kilcawley
Secretary, L. R. Douglass

Respectfully submitted on behalf of the committee,

C. A. HOGENTOGLER,
Chairman.

L. R. DOUGLASS,
Secretary.

---

[4] See Editorial Note, below.

[5] Procedures for Testing Soils, issued by A.S.T.M. as separate publication, September, 1944, p. 194.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-18 and Committee D-4 on Road and Paving Materials presented to the Society through Committee E-10 on Standards a proposed Tentative Method of Test for Determining Cement Content of Soil-Cement Mixtures. The new tentative method was accepted by Committee E-10 on August 28, 1944, and appears in the 1944 Book of A.S.T.M. Standards, Part II, p. 1402, under the designation D 806 - 44 T.

REPORT OF COMMITTEE D-19

ON

WATER FOR INDUSTRIAL USES

Committee D-19 on Water for Industrial Uses and its subcommittees held meetings in Pittsburgh, Pa., on June 28 and 29, 1943.

The committee sponsored a session on water at the 1943 Annual Meeting in the form of a Symposium on the Identification of Water-Formed Deposits, Scales, and Corrosion Products by Physico-Chemical Methods.[1]

The committee is sponsoring a water session at this Annual Meeting of the Society, in the form of a Round-Table Discussion on Organizing the Classification of Industrial Waters, the program comprising the following four papers[2] and an introduction by W. C. Schroeder, Ass't. Chief, Fuels and Explosive Service, U. S. Bureau of Mines, Washington, D. C.:

"Typical Water Analyses for Classification with Reference to Industrial Use," by W. D. Collins, Chemist in Charge, Water Quality Division, U. S. Geological Survey, Washington, D. C.

"The Use of Selected Waters in Pulp and Paper Manufacture," by L. B. Miller, Chairman, Water Committee, Technical Association of the Pulp and Paper Industry, Ambler, Pa.

"Treatment of Various Types of Waters for Operating Pressures above 400 psi.," by R. E. Hall, Director, Hall Laboratories, Inc., Pittsburgh, Pa.

"Boiler Feedwater for Between 100 to 400 psi. Boiler Pressure," by J. A. Holmes, Assistant Vice-President, National Aluminate Corp., Chicago, Ill.

A.S.T.M. Manual on Water for Industrial Uses.—Subcommittee II, Editorial, prepared and circulated to the membership of the committee a proposed outline of the chapters to be included in a Manual on Water for Industrial Uses. This project meets with general favor and consideration is now being given to it by Committee E-6 on Papers and Publications.

The various chapters cover: Object of manual, uses of industrial water, difficulties caused by water during use, composition of water supplies, sampling of industrial water, analysis of industrial water, identification of deposits and products of corrosion, testing behavior of water, and treatment of water for industrial use.

REORGANIZATION OF SUBCOMMITTEES[3]

One of the major activities of the technical subcommittees during the year was the appointment of personnel to the subject-subsections organized within the sections of the various subcommittees. The subject-subsections now functioning are as follows:

Subcommittee III on Methods of Sampling:

Section A on Water: Sampling of Water at Atmospheric Pressure, Sampling of Locomotive Boiler Water, Sampling of Marine Boilers, Sampling of

---

[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 43, pp. 1240 to 1310 (1943).

[2] See p. 1051.

[3] Outline of reorganization of subcommittees published in ASTM BULLETIN, No. 124, October, 1943, p. 40.

Stationary Boilers, Sampling of Unfired Vessels, and Specifications for Sampling Equipment.

Section B on Resultant Deposits: Organization of subject-subsections now under way.

NOTE.—The activities of the subject-subsections of Section A are intended to complete the subject matter covered in the outline previously developed, and as set forth in the 1940 Annual Report of Committee D-19.[4]

Subcommittee IV on Methods of Analysis:

Section A on Chemical Methods: Dissolved Oxygen, Silica, Alkali Metals, Dissolved Solids, Oxides of Aluminum, Iron, Manganese, and Nitrogenous (Nitrates).

Section B on Electrometric Methods: Subject-subsection to be organized.

Section C on Special Methods: Polarizing Microscope, Electron Microscope, Spectrographic, and X-ray Diffraction.

Subcommittee VI on Methods of Testing:

Section A on Corrosivity: Embrittlement Detector.

Section B on Stability: Subject-subsections to be organized.

Several of the subject-subsections have prepared in preliminary form the substance intended for standard methods. Such methods after being prepared in A.S.T.M. form will be referred to the subcommittee and the main committee for action. The following subject-subsections have such preliminary work in hand: Sampling of Stationary Boilers, Dissolved Oxygen, Silica, Alkali Metals, and Embrittlement Detector.

The members of the subject-subsection on Dissolved Oxygen have participated in a station testing program utilizing an operating deaerator. The object of this test program was to secure data to show what agreement in results could be secured when more than one operator was determining the dissolved oxygen content by the same method. Two methods for determining the dissolved oxygen content were used. Such plant testing may prove to be a valuable contribution and since four analysts participated in a test program of approximately one week's duration the results, when available, should be significant.

The Society was represented by Max Hecht and F. N. Speller, at the meeting of the Executive Subcommittee of the Joint Research Committee on Boiler Feedwater Studies, held December 1, 1943, at New York, N. Y.

The Society was represented by Max Hecht at a meeting of the Subcommittee on Care of Steam Boilers in Service of the Boiler Code Committee, American Society of Mechanical Engineers, held in Pittsburgh, Pa., on June 29, 1943. The work of the revision subcommittee, reported in the 1943 Annual Report,[5] is progressing actively, three of the members having made preliminary reports.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee II, Editorial (E. P. Partridge, chairman).—The major objective of the subcommittee is arranging for the A.S.T.M. Manual on Water for Industrial Uses as discussed earlier in this report.

Definitions of terms used in connection with industrial waters are being prepared.

Arrangements were made for preparation of early drafts of methods with respect to form as well as content by including a member of the editorial subcommittee on each subsection responsible for the development of methods.

---

[4] *Proceedings*, Am. Soc. Testing Mats., Vol. 40, p. 428 (1940).

[5] *Proceedings*, Am. Soc. Testing Mats., Vol. 43, p. 396 (1943).

Subcommittee III on Methods of Sampling (D. K. French, chairman).—The major activities of the subcommittee during the year have been devoted to the organization of sections and subject-subsections as detailed earlier in this report. Section A on Sampling of Liquids (M. D. Baker, chairman) and Section B on Sampling of Resultant Deposits (F. R. Owens, chairman) will formulate methods in fields heretofore not covered in the technical literature. This is particularly true with respect to the work of Section B. An information circular has been furnished to the members of Section B and after an analysis of returns specific subject-subsections will be organized. A preliminary draft of a method for sampling water in stationary boilers based upon present practice was prepared by a special group consisting of D. K. French (chairman), J. A. Holmes, Eli Mandel, and A. H. Reynolds.

During the past two years members of the committee had been circularized to secure their operating experiences and the results of these experiences have been incorporated in the draft. This preliminary draft is now in the hands of the subject-subsection on Sampling of Stationary Boilers (P. B. Place, chairman).

Subcommittee IV on Methods of Analysis (H. C. Miller, chairman).—Section A on Chemical Methods and Section C on Special Methods, under the chairmanship of A. A. Berk and C. E. Imhoff, respectively, have completed the organization of their subject-subsections as noted earlier in this report.

Preliminary drafts of methods of test for dissolved oxygen, silica, and alkali metals in water have been prepared and are being discussed within the membership of each subsection. While primary concern is being given to referee methods, nonreferee methods will be included, the latter being intended for routine and control application. The other subsections are making plans for their work during the next year.

The four subject-subsections organized under Section C are now considering plans for their work but will not have any preliminary drafts available during this year.

Subcommittee V on Classification (W. C. Schroeder, chairman).—The work of the subcommittee has been concerned largely with the development of a method of classifying water which would be sufficiently flexible for widespread industrial use. Formulas or graphs that have been suggested for specific cases did not seem suitable for application to the great variety of processes in which water is of prime importance. Such methods of classification frequently result in arbitrary distinctions for individual samples which are not in accord with the known facts. As a result of this situation, the subcommittee is now attempting to classify waters by comparing their analyses with the analyses of standard samples whose characteristics in connection with definite industrial uses are known and can be fully described.

The first step toward the application of this method of classification has been the organization of a round-table discussion, as mentioned earlier in this report, to consider the samples that have been selected as standard and to show how these standards are used in classifying water for paper manufacture and for use in high- and low-pressure boilers. The four papers in this round-table discussion will be given at the 1944 Annual Meeting, to acquaint engineers with the method of classification that is being tried and to bring about widespread discussion.

Subcommittee VI on Methods of Testing (V. V. Kendall, chairman).—The subsection on the embrittlement detector has prepared in preliminary form and circulated among its members a method for determining the embrittling characteristics of boiler water.[6] No other activity was initiated within the subcommittee.

The present officers of the committee were re-elected for the ensuing term of two years.

This report has been submitted to letter ballot of the committee, which consists of 70 members; 52 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

MAX HECHT,
Chairman.

R. E. HALL,
Secretary.

---

[6] See Editorial Note below.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-19 presented to the Society through Committee E-10 on Standards a proposed Tentative Method of Field Test for Tendency of Boiler Water to Cause Embrittlement. The new tentative method was accepted by Committee E-10 on August 28, 1944, and appears in the 1944 Book of A.S.T.M. Standards, Part III, under the designation D 807 – 44 T.

JOINT RESEARCH COMMITTEE
ON
BOILER FEEDWATER STUDIES

During the period from April 1, 1943, to March 31, 1944, the interest and activities of the Joint Research Committee on Boiler Feedwater Studies have been centered on certain problems which are summarized below:

Silica and Turbine Blade Deposits.—Subcommittees have been active in connection with the problems of silica and turbine blade deposits. A limited amount of research, not sponsored by the committee, is under way. Papers and reports on this subject will be presented at a later date.

Potassium Salts in Place of Sodium Salts for Treating of Boiler Feedwater.—The use of potassium salts is receiving widespread interest. The Joint Research Committee sponsored a session at the A.S.M.E. Annual Meeting which was devoted to the presentation of a paper dealing with the physical-chemical properties of potassium salts in boiler waters.[1] Further papers on operating experiences with potassium salts are scheduled for the near future.

The Effect of Potassium Salts on the Embrittlement of Boiler Steel.—Research is now in progress to determine the effect of potassium salts on the embrittlement of boiler steel. No date has been scheduled for presenting the results of this investigation.

Data on New Cases of Boiler Cracking.—Subcommittee VI of the Joint Research Committee is undertaking the compilation of essential data in connection with the new cases of boiler metal cracking.

Formation of Black Oxide Deposits in High-Pressure Boilers.—It is becoming increasingly apparent that this problem warrants rather thorough investigation.

The officers of the Joint Research Committee take this opportunity to express their keen appreciation of the valuable assistance and advice that have been given to them from time to time by the members and officers of the American Society for Testing Materials.

Respectfully submitted on behalf of the committee,

C. H. Fellows,
Chairman.

---

[1] R. E. Hall, "A New Approach to the Problem of Conditioning Water for Steam Generation," *Transactions*, Am. Soc. Mechanical Engrs. (1944).

REPORT OF COMMITTEE D-20

ON

PLASTICS

Since the June, 1943, meeting in Pittsburgh, Pa., Committee D-20 on Plastics and its subcommittees have held two meetings: in New York, N. Y. in October, 1943, and in Philadelphia, Pa. in February, 1944. A Symposium on Plastics was held in Philadelphia, in February, 1944, under the sponsorship of the Philadelphia District Committee with the cooperation of Committee D-9 on Electrical Insulating Materials and Committee D-20.

The organization of Subcommittee IX on Molds and Molding Processes has been completed and W. L. Hess has been appointed chairman. A special committee on identification tests has been appointed, under the chairmanship of L. Boor. D. L. Gibb resigned as second vice-chairman of Committee D-20 and W. E. Gloor was elected to fulfill his term.

The committee sponsored a revised compilation of "A.S.T.M. Standards on Plastics," issued in October, 1943. This publication contains all of the specifications, test methods, and recommended practices developed by the committee and, in addition, includes a number of related standards prepared by several other A.S.T.M. committees.

Subsequent to the 1943 Annual Meeting, Committee D-20 presented to the Society, through Committee E-10 on Standards a number of recommendations which are listed in Table I together with the results of the letter ballot vote in Committee D-20 and the date of acceptance by Committee E-10. The new and revised standards have been assigned A.S.T.M. serial designations indicated and those accepted prior to October, 1943, appear in the new compilation of "A.S.T.M. Standards on Plastics." They are all available in separate reprint form and will appear in the 1944 Book of A.S.T.M. Standards.

Recommendations Affecting Standards

As the result of the year's work, the committee is submitting twelve new tentative standards, revision of fifteen tentative standards, one tentative revision of a standard, and is recommending the adoption of three tentative standards as standard. The standards affected are listed in Table II and the recommendations are included in the Appendix.

The proposed tentative specifications have been developed as part of the program of supplying urgently needed specifications on all commercially important plastics for use by the Army, Navy, Federal Government, and consumers in general. The proposed tentative methods of test are needed to supply new data in the cases of reflection and transmission characteristics, and the stability of chlorine-containing plastics, more accurate data in the case of flexural properties, and standardized procedures in the cases of indentation hardness and specific gravity. The proposed recommended practices have been developed in an attempt to standardize the tech-

TABLE I—RECOMMENDATIONS ACCEPTED BY COMMITTEE E-10 ON STANDARDS, INCLUDING RECORD OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
New Tentative Specifications for:			
Nonrigid Vinyl Chloride-Acetate Plastics (D 742 – 43 T), *accepted August 30, 1943*	31	1	22
Nonrigid Ethyl Cellulose Plastics (D 743 – 43 T), *accepted August 30, 1943*	30	1	23
Nonrigid Vinyl Chloride Plastics (D 744 –43 T), *accepted August 30, 1943*	30	1	23
Nonrigid Vinyl Butyral Plastics (D 745 – 43 T), *accepted September 7, 1943*	28	5	21
o-Dichlorobenzene (Incorporated in Specifications D 729), *accepted January 1, 1944*	27	3	35
*Enclosures for Small Testing Machines for Tests at Subnormal and Supernormal Temperatures of Electrical Insulating Materials and Plastics (D 760 - 44 T), *accepted February 8, 1944*	47	5	13
*Servicing Units for Tests at Subnormal and Supernormal Temperature of Electrical Insulating Materials and Plastics (D 761 – 44 T), *accepted February 8, 1944*	45	7	13
New Tentative Methods of Test for:			
Brittleness of Nonrigid Plastics (D 746 – 43 T), *accepted August 30, 1943*	36	1	17
Stiffness in Flexure of Nonrigid Plastics (D 747 – 43 T), *accepted August 30, 1943*	38	2	14
Resistance of Plastics to Accelerated Service Conditions (D 756 – 44 T), *accepted January 19, 1944*	46	3	16
Flammability of Plastics, Self-Extinguishing Type (D 757 - 44 T), *accepted January 19, 1944*	46	5	14
Tensile Strength and Compressive Strength of Plastics at Subnormal and Supernormal Temperatures (D 759 – 44 T), *accepted January 19, 1944*	45	4	16
Testing Polystyrene Molding Compounds (Incorporated in Specifications D 703), *accepted January 1, 1944*	34	2	29
New Tentative Recommended Practice for:			
Impact Strength Tests of Plastics at Subnormal and Supernormal Temperatures (D 758 – 44 T), *accepted January 19, 1944*	47	4	14
Revision of Tentative Specifications for:			
Polystyrene Molding Compounds (D 703 – 43 T), *accepted August 30, 1943*	27	0	27
Cellulose Acetate Molding Compounds (D 706 – 43 T), *accepted August 30, 1943*	30	0	24
Cellulose Acetate Butyrate Molding Compounds (D 707 - 43 T), *accepted August 30, 1943*	29	0	25
Revision of Tentative Method of Test for:			
Compressive Strength of Plastics (D695 – 44 T), *accepted January 1, 1944*	48	0	17

* Submitted jointly with Committee D-9 on Electrical Insulating Materials.

TABLE II.—ANALYSIS OF LETTER BALLOT VOTE.

Items	Affirmative	Negative	Ballots Marked "Not Voting"
I. NEW TENTATIVE STANDARDS			
Spec. for Cellulose Acetate Plastic Sheets	29	0	26
Spec. for Ethyl Cellulose Molding Compounds	34	0	38
Spec. for Methacrylate Molding Compounds	32	2	38
Spec. for Nylon Injection Molding Compound	30	2	40
Test for Flexural Testing of Plastics	45	1	9
Test for Indentation Hardness of Plastics	44	3	17
Test for Luminous Reflectance and Transmission Characteristics and Color of Plastic Materials	29	1	36
Test for Specific Gravity of Plastics	53	2	9
Short-Time Stability at Elevated Temperatures of Plastics Containing Chlorine	31	0	33
Rec. Practice for Determination of the Permanent Effect of Heat on Plastics	46	2	11
Rec. Practice for Accelerated Weathering of Plastics Using S-1 Bulb and Fog Chamber	39	3	13
Rec. Practice for Molding Impact Specimens of General Purpose Phenolic Materials	34	1	29
II. REVISIONS OF TENTATIVE STANDARDS			
Spec. for Nonrigid Vinyl Butyral Plastics (D 745 – 43 T)	32	2	38
Spec. for Vinylidene Chloride Molding Compounds (D 729 – 44 T)	24	0	35
Spec. for Cellulose Acetate Molding Compounds (D 706 – 43 T)	33	0	33
Spec. for Cellulose Acetate Butyrate Molding Compounds (D 707 – 43 T)	25	0	39
Spec. for Cellulose Nitrate (Pyroxylin) Plastic Sheets, Rods, and Tubes (D 701 – 43 T)	33	0	38
Spec. for Melamine-Formaldehyde Molding Compounds (D 704 – 43 T)	30	2	40
Spec. for Nonrigid Vinyl Chloride-Acetate Plastics (D 742 – 43 T)	34	0	38
Spec. for Nonrigid Ethyl Cellulose Plastics (D 743 – 43 T)	32	0	40
Spec. for Nonrigid Vinyl Chloride Plastics (D 744 – 44 T)	33	0	39
Test for Brittleness of Nonrigid Plastics (D 746 – 43 T)	37	1	26
Test for Distortion Under Heat of Molded Electrical Insulating Materials (D 648 – 41 T)	44	4	16
Test for Measuring Relative Mobility of Thermosetting Molding Powder (D 731 – 43 T)	33	0	31
Test for Tensile Properties of Plastics (D 638 – 42 T)	50	0	14
Test for Haze of Transparent Plastics by Photoelectric Cell (D 672 – 42 T)	44	3	21
Methods of Conditioning Plastics and Electrical Insulating Materials for Testing (D 618 – 41 T)	40	3	16
III. TENTATIVE REVISION OF STANDARD			
Test for Deformation of Plastics Under Load at Elevated Temperatures (D 621 – 43)	40	1	22

TABLE II.—(*Continued*)

Items	Affirmative	Negative	Ballots Marked "Not Voting"
IV. ADOPTION OF TENTATIVE STANDARDS AS STANDARD			
Test for Flammability of Plastics Over 0.050 in. in Thickness (D 635 - 41 T)	46	1	17
Test for Mar Resistance of Plastics (D 673 - 42 T)	39	1	24
Test for Coefficient of Linear Thermal Expansion of Plastics (D 696 - 42 T)	45	1	18

nique employed in determining the effects produced on plastics by environmental conditions in the cases of effect of heat and accelerated aging. The recommendations on molding impact specimens of general purpose phenolic materials are the first of this type; similar recommendations are needed and are being developed for other materials.

The revisions in the tentative specifications and methods of test are recommended, in order to bring them up to date, to supply additional or more adequate data, or to make them more useful. Because of the current urgent need for specifications and test methods, many are being issued in record time with the attendant necessity for early and frequent revision.

These recommendations have been submitted to letter ballot of the committee which consists of 117 voting members, with the results shown in Table II.

ACTIVITIES OF SUBCOMMITTEES

As indicated by the recommendations accepted by Committee E-10 (Table I) and the recommendations proposed (Table II), all of the subcommittees have been very active during the past year. This activity is being maintained and a brief résumé of projects now in progress follows.

Subcommittee I on Strength Properties (M. H. Bigelow, chairman).—A proposed tentative method of test for tensile properties of thin plastic sheets and films has been submitted to letter ballot in the subcommittee. Work on high-speed and repeated impact is progressing, especially since Subcommittee VIII is working on the problem and many ideas are being suggested. A rod-type machine for shear tests has been built and is being used in a round-robin test. The present type plate shear machine is being revised to improve clamping. A proposed method of test for bearing strength has been suggested and is now under study. A study is being made of the advisability of setting up simplified identification tests.

Subcommittee II on Hardness Properties (L. Boor, chairman).— Although the Rockwell hardness test has been revised, work is being continued in an effort to shorten the testing time and to develop a more satisfactory method for determining indentation hardness. Also the Rockwell machine has been referred to Committee E-1 on Methods of Testing for further specification and elucidation. The work on scratch hardness is progressing. Tests are being run on the Bierbaum and Olsen testers as well as the Taber abrader. A method for determining blocking resistance has been proposed and is now under discussion.

Subcommittee III on Thermal Properties (W. A. Zinzow, chairman).—A proposed method of test for measuring the coefficient of cubical expansion has been sent out for subcommittee comment. An alternate method of determining flow properties of thermoplastic materials, especially designed for materials such as polystyrene is under development. The work on deformation under load is being continued. A method is being developed for intermediate materials such as the softer rigid thermoplastics.

Subcommittee IV on Optical Properties (W. F. Bartoe, chairman).—Work is being continued on methods of measuring haze and light transmission. Tests are under way to evaluate the "double-vision" or "double-reflection" method of examining curved transparent plastics for optical defects. A number of definitions are also under consideration.

Subcommittee V on Permanence Properties (J. H. Teeple, chairman).—Work is being continued on accelerated weathering tests. It is proposed to develop a recommended testing procedure using a standard carbon-arc light source. Tests are under way to determine a satisfactory set of accelerated service conditions to allow testing of materials which are essentially stable but will not withstand temperatures substantially above room temperature. Considerable interest has been aroused in the semipermanent effect of heat on plastics and an extensive program of work covering this field has been outlined. The section on water vapor permeability is making a study of existing methods in an effort to make a recommendation for materials which are very impervious to moisture.

Subcommittee VI on Specifications (G. M. Kline, chairman).—Because of the urgent need for specifications covering all plastic materials, this subcommittee has been extremely active. In addition to the regular scheduled meetings, it has been necessary to hold a number of special meetings. Specifications are now being written for polystyrene sheet materials and allyl and polyethylene plastics. Revisions are being prepared for vinyl resins, and all the nonrigid plastics. Considerable work is being done on classification, especially in the case of nonrigid plastics. This classification of the nonrigid plastics is being prepared at the request of Committee D-11 on Rubber Products and, when finally completed and approved, is intended for inclusion in the Tentative Specifications for Rubber and Synthetic Rubber Compounds for Automotive and Aeronautical Applications (D 735–43 T). During the year a section on adhesives was organized and a number of specifications in this field are being written. It is contemplated that this work on adhesives will be transferred to the new A.S.T.M. Committee on Adhesives as soon as its organization is completed.

Subcommittee VII on Analytical Properties (P. D. Brossman, chairman).—Development work on the determination of insoluble (cross-linked) material in polystyrene is in process. A method for determination of acetyl and butyryl in cellulose acetate butyrate is being written.[1] Work is being done on determination of free phenol and free formaldehyde in phenolformaldehyde resins, and on determination of stability and residual solvent of cellulose nitrate plastics. Other problems under consideration are the determination of plasticizer, residual solvent, pigment, and fillers in cellulose plastics and the nonvolatile content of synthetic-resin impregnants.

Subcommittee VIII on Research (H. K. Nason, chairman).—The problem of impact testing is being continued. To date, most of the work has covered modifications of the Izod method and methods involving a falling ball dropped either vertically or along an inclined plane. It is proposed to study other methods including repeated impact and impact under tension. The subcommittee is also studying the flow properties of plastic materials.

Subcommittee IX on Molds and Molding Processes (W. L. Hess, chairman).—A method for molding 5 by $\frac{1}{2}$ by $\frac{1}{2}$ in. test bars from mica-filled phenolic materials is being compiled. A two-cavity injection mold for tension and weld test specimens has been approved by the section and will soon be ready for letter ballot. A method is being developed for determining the bulk factor of nonpouring compounds. A special section on identification tests is engaged in evaluating the spiral mold and other methods for determining flow properties of materials.

---

[1] See Editorial Note, p. 509.

Special Committee on Identification Test Methods (L. Boor, chairman).—This committee was set up to study the desirability and need of developing simple test methods which could be used to identify and control material received. Of particular interest are such properties as moisture content, bulk factor, specific gravity, size of granules, and flow properties. As a result of the interest shown, the committee is now engaged in compiling existing methods and in addition is running a round-robin test on various methods of flow measurement such as the Rahm spiral and a method developed by the Radio Corporation of America. Other work has been referred to the appropriate subcommittees.

The present officers of the committee have been re-elected for the ensuing term of two years.

This report has been submitted to letter ballot of the committee which consists of 117 voting members; 64 members returned their ballots of whom 52 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the committee,

ROBERT BURNS,
Chairman.

L. W. A. MEYER,
Secretary.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee D-20 presented to the Society through Committee E-10 on Standards the following recommendations:

Revision of Tentative Specifications for:

Vinyl Chloride-Acetate Resin Sheets (D 708 - 43 T),
Vinyl Chloride-Acetate Molding Compounds (D 728 - 43 T),
Laminated Thermosetting Materials (D 709 - 43 T), recommended jointly by Committee D-20 and Committee D-9 on Electrical Insulating Materials,

Tentative Methods of:

Chemical Analysis for Acetyl and Butyryl in Cellulose Acetate Butyrate (D 817 - 44T),
Test for Measuring the Flow Properties of Thermoplastic Molding Materials (D 569 - 44 T), to replace Standard Method D 569 - 43,
Test for Deformation of Plastics Under Load (D 621 - 44 T), to replace Standard Method D 621 - 43,

Revision of Tentative Method of:

Test for Resistance of Plastics to Accelerated Service Conditions (D 756 - 44 T), and

Tentative Recommended Practices for:

Molding Impact, Flexural and Tensile Specimens of Shock Resistant Phenolic Materials, and
Molding Impact, Flexural and Tensile Specimens of Mica Filled Phenolic Materials, to be combined with the other Tentative Recommended Practices for Molding Specimens of Phenolic Materials and issued under the designation D 796 - 44 T.

The proposed revisions in Tentative Specifications D 708 and D 728 were accepted by Committee E-10 on August 28, 1944, the revision of Tentative Standards D 709 and D 756 and Tentative Methods D 817 and D 569 were accepted on December 11, 1944, Tentative Methods D 621 on December 13, 1944, and the revision of Tentative Standard D 796 on December 22, 1944. The new and revised tentatives appear in the 1944 Book of A.S.T.M. Standards, Part III.

On January 9, 1945, the Standards Committee accepted the joint recommendation of Committee D-20 and Committee D-9 on Electrical Insulating Materials that the Tentative Methods of Conditioning Plastics and Electrical Insulating Materials for Testing (D 618 - 44 T) be revised. The revised tentative methods also appear in the 1944 Book of A.S.T.M. Standards, Part III.

APPENDIX

PROPOSED REVISIONS IN STANDARDS FOR PLASTICS

In this Appendix are given proposed revisions in certain standards and tentative standards covering plastics which are referred to earlier in this report.[1] These standards and tentative standards appear in their present form in either the 1942 Book of A.S.T.M. Standards, Part III, or the 1943 Supplement, Part III, as indicated by the final number in the A.S.T.M. designation.

Tentative Specifications for Nonrigid Vinyl Butyral Plastics (D 745 – 43 T):

Section 2.—Change the second sentence of the note from its present form: "A series of compounds with small differences in properties can be produced" to read as follows: "Compounds varying by small increments through a wide range of properties can be produced."

Section 3 (*b*).—Add a note to this section to read as follows:

NOTE.—Nonrigid vinyl butyral plastics are available in the following forms:

In milled or calendered slabs, sheets, and rolls.

In the form of compounded dough, and dopes and coating solutions.

Table II.—Change values for elongation at rupture, min., per cent for grades 5, 6, and 7 from "250, 250," and "300," respectively, to read "225".

Delete the requirements for compression set at 77 F. for grades 4, 5, 6, and 7. Delete requirements for Type I, grades 1 and 2, which are to be specified at a later date.

Tentative Specifications for Vinylidene Chloride Molding Compounds (D 729 – 43 T):

Section 4 (*b*).—Add the following to the table on detail requirements:

Impact strength (Izod), min., ft-lb. per in. of notch	at 25 C. (77 F.)	0.5
	at -40 C. (-40 F.)	0.1
Weight loss on heating (72 hr. at 82 C. (180 F.)), max., per cent		2.0 in.

Section 6.—Add new Paragraphs (*k*) and (*l*) to read as follows:

(*k*) *Impact Strength* (*Izod*).—Method A of the Tentative Methods of Test for Impact Resistance of Plastics and Electrical Insulating Materials (A.S.T.M. Designation: D 256).[2] In impact tests at low temperatures the conditioned test specimens shall be exposed for 24 hr. at −40 ± 1 C. (−40 ± 2 F.) and tested at that temperature.

(*l*) *Weight Loss on Heating*.—Test specimen 3 by 1 by $\frac{1}{8}$ in. shall be conditioned for 48 hr. over anhydrous calcium chloride at 25 ± 1 C. (77 ± 2 F.). The specimens shall be weighed and then placed in a circulation air oven for 72 hr. at 82 ± 1 C. (180 ± 2 F.). The specimens shall be supported flatwise on a screen in the oven. Upon removal from the oven, the specimens shall be cooled in a desiccator over anhydrous calcium chloride to 25 ± 1 C. (77 ± 2 F.). The specimens shall then be weighed and the percentage weight loss on heating calculated on the basis of the conditioned weight.

REVISIONS OF TENTATIVE STANDARDS

Tentative Specifications for Nonrigid Vinyl Chloride Plastics (D 744 – 44 T):

Table I.—Change to read as follows:

---

[1] See p. 505.

[2] 1943 Supplement to Book of A.S.T.M. Standards, Part III, p. 249.

NOTE.—The hardness values and low-temperature classifications in this table are included in these specifications for purposes of classification only and are not specific requirements to be met.

Type	Grade	Durometer Hardness[a]	A.S.T.M. Hardness[b]	Low-Temperature Classification[c]
I. Unfilled (plasticized with dioctyl phthalate or equivalent)	1...	90 ± 10	23 ± 4	N
	2...	80 ± 10	30 ± 5	N
	3...	80 ± 10	38 ± 5	F
	4...	70 ± 10	48 ± 5	F
II. Heat and flame resistant	5...	80 ± 10	40 ± 7	N
III. Cold resistant	6...	80 ± 10	25 ± 6	F
	7...	80 ± 10	30 ± 7	FF
IV. Filled	8...	90 ± 10	22 ± 5	N
	9...	90 ± 10	27 ± 6	N

[a] Tentative Method of Test for Indentation of Rubber by Means of the Durometer (A.S.T.M. Designation: D 676).

[b] Standard Method of Test for Hardness of Rubber (A.S.T.M. Designation: D 314).

[c] A low-temperature classification of FF indicates that the material does not fail at −70 F., a classification of F indicates that the material does not fail at −40 F., and a classification of N indicates that the material fails at −40 F. when tested in accordance with the Tentative Method of Test for Low-Temperature Brittleness of Rubber and Rubber-Like Materials (A.S.T.M. Designation: D 736).

Table II.—Change to read as shown in the accompanying Table I:

Tentative Method of Test for Determining Relative Mobility of Thermosetting Molding Powder (D 731 – 43 T):

Section 5 (c).—Change to read as follows, adding a new Note 4 and renumbering the present Note 4 as Note 5.

(*c*) A load of 5000 lb. shall be used on the mold to make the initial test. If the cup is not completely filled, the test shall be repeated, increasing the load used by increments of 5000 lb. until a completely filled cup is obtained, and the closing time is not less than 10 sec. (Note 4). The corresponding gage points shall be determined by dividing the desired load by the area of the ram in square inches. The gage pressure shall be maintained constant within plus or minus 50 lb.

NOTE 4.—The preferred pressure to be used is that pressure which will result in a closing time of not less than 10 nor more than 40 sec. Some molding powders are formulated to give long

TABLE I.—DETAIL REQUIREMENTS FOR NONRIGID VINYL CHLORIDE PLASTICS.

	Type I				Type II	Type III		Type IV	
	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Grade 6	Grade 7	Grade 8	Grade 9
Specific gravity, 25/25 C. (77/77 F.), max.	1.38	1.34	1.31	1.30	1.40	1.39	1.38	1.52	1.65
Specific gravity, 25/25 C. (77/77 F.), min.	1.22	1.21	1.19	1.18	1.29	1.21	1.19	1.39	1.49
Tensile strength, min., psi.	2 600	2 200	1 800	1 400	2 200	2 600	2 200	1 400	1 000
Elongation at rupture, min., per cent	350	330	360	390	250	330	360	200	250
Stiffness, psi. at 25 C. (+77 F.) max.	2 750	1 650	1 200	800	1 100	2 200	1 500	[b]	[b]
Stiffness, psi. at 25 C. (+77 F.) min.	1 800	900	700	500	700	1 000	800	[b]	[b]
Stiffness, psi. at −40 C. (−40 F.), max	450 000	350 000	275 000	200 000	700 000	170 000	100 000	[b]	[b]
Stiffness, psi. at −57 C. (−70 F.), max	600 000	500 000	450 000	400 000	1 000 000	300 000	130 000	[b]	[b]
Tear resistance, min., lb. per in.	550	450	350	250	400	400	300	350	250
Brittle temperature, max., deg. Cent.	−20	−25	−29	−33	−2	−46	−51	[b]	[b]
Brittle temperature, max., deg. Fahr.	−4	−13	−30	−27	+28	−50	−60	[b]	[b]
Water absorption, max., per cent, weight gain plus soluble matter loss	0.40	0.50	0.65	0.60	0.60	1.75	2.25	[b]	[b]
Water absorption, max., per cent, soluble matter loss	0.10	0.15	0.15	0.20	0.20	1.50	2.00	[b]	[b]
Flammability (burning rate), max., sq. in per sec., 0.020 in. thick.	0.4	0.4	0.4	0.5	[a]	0.6	0.6	[b]	[b]
Flammability (burning rate), max., sq. in per sec., 0.040 in. thick.	[a]	[a]	[a]	0.2	[a]	0.3	0.3	[a]	[b]
Weight loss on heating (72 hr. at 82 C. (180 F.)), max., per cent	0.6	0.7	0.8	0.8	0.8	2.0	2.5	0.5	1.7
Increase in stiffness at 25 C. (77 F.) after heating, max., per cent	15	15	15	15	15	30	30	15	30
Increase in brittle temperature after heating, max., deg. Cent.	2	2	2	2	2	5	5	[b]	[b]
Increase in brittle temperature after heating, max., deg. Fahr.	4	4	4	4	4	9	9	[b]	[b]
Thermal stability, max., mg. HCl per g.	2	2	2	2	2	2	2	2	2
Dielectric strength (short-time test), min., v. per mil	425	400	400	350	350	350	325	400	350
Oil resistance, max., per cent loss in weight	....	....	....	....	0.15	....	....	....	....
Deformation under load, 100 psi. pressure at 70 C. (158 F.):									
Total deformation, max., per cent	25	30	35	45	35	25	35	15	30
Recovery, min., per cent	75	75	65	60	65	60	70	70	75

[a] Self-extinguishing.

[b] To be specified at a later date.

slow closing times with minimum molding pressures and in such cases, it is desirable to use pressures in excess of that required to completely fill the cup so as to obtain closing times of less than 40 sec.

Tentative Method of Test for Tensile Properties of Plastics (D 638 – 42 T):

Section 2.—Add the following new definition:

(*i*) *Offset Yield Stress* is the stress at which the stress-strain curve departs from linearity by a specified percentage of deformation (offset). The method for determining the offset yield stress is prescribed in the Standard Definitions of Terms Relating to Methods of Testing (A.S.T.M. Designation: E 6)[3] under definition of yield strength, Paragraph 2 (*a*) on "Offset Method." The amount of offset shall always be stated, for example, 0.2 per cent offset yield stress.

TABLE II.—WATER ABSORPTION REQUIREMENTS FOR MOLDED RODS.

Diameter, in.[a]	Water Absorption, After 24-hr. Immersion, max., per cent							
	Type I		Type II				Type III	
	Grade XX	Grade XXX	Grade C	Grade CE	Grade L	Grade LE	Grade A	Grade AA
⅛	....	1.5	....	....	....	....	....	....
¼	1.5	1.0	2.5	1.5	1.5	1.2	2.0	....
½	1.0	0.75	2.0	1.0	1.2	0.90	1.5	1.25
1	1.0	0.75	2.0	1.0	1.2	0.90	1.5	1.25
Over 1 to 2, incl.	1.3	0.75	1.5	1.2	1.2	1.1	1.75	1.75

[a] Intermediate diameters under 1 in. take the value for the next smaller diameter.

Insert this same definition of offset yield stress as number 23 under Definitions in the Appendix, and renumber the succeeding definitions accordingly.

Section 4.—Change Paragraph (*a*) from its present form to read as follows:

4. (*a*) *Sheets, Plates and Molded Plastics.*—The test specimen shall conform to the dimensions shown in Fig. 1. This specimen may be prepared by machining operations from materials in sheet, plate, slab, or similar form, or it may be prepared by molding of the material to be tested.

Add the following new Paragraphs (*b*) and (*c*) and reletter the succeeding paragraphs accordingly:

(*b*) *Tubes.*—The test specimen shall be as shown in Fig. 2. The length shall be 10 in. plus four times the inside diameter. When the wall thickness of the tube is $\frac{1}{8}$ in. or greater, a groove $2\frac{1}{4}$ in. in width in the flat portion and $\frac{1}{32}$ in. in depth, with corners rounded to a radius of 3 in., shall be machined around the outside of the specimen at the center. Steel or brass plugs, having diameters such that they will fit snugly inside the tube and having a length 2 in. plus twice the diameter, shall be placed in the ends of the specimen to prevent crushing. They can be located in the tube conveniently by separating and supporting them on a metal rod, the lower end of which is screwed into the lower plug and the upper end of which rests loosely in a socket. Details of plugs and test assembly are shown in Fig. 2.

(*c*) *Rods.*—The test specimen as shown in Fig. 3 shall be about 12 in. in length. When the diameter of the rod is $\frac{1}{4}$ in. or greater, a groove $2\frac{1}{4}$ in. in width in the flat portion and $\frac{1}{32}$ in. in depth, with corners rounded to a radius of 3 in., shall be machined around the specimen at the center.

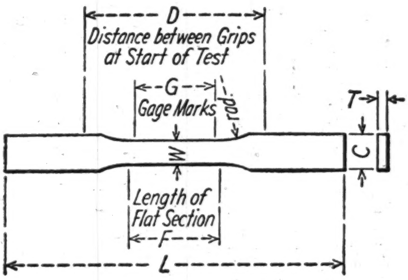
Delete the present Fig. 1 including the notes and substitute for it the accompanying new Fig. 1 including the new notes. Add the accompanying new Figs. 2 and 3.

Section 8.—Change Paragraph (*b*) to read as follows:

(*b*) The width and thickness of the flat specimen (Fig. 1) shall be measured to the nearest 0.001 in. at several points along its length. The diameter of rod specimens, and the inside and outside diameters of tube specimens, shall be measured to the nearest 0.001 in. at at least two points 90 deg. apart; these measurements shall be made at the groove for specimens so constructed. Record the minimum

---

[3] 1942 Book of A.S.T.M. Standards, Part III, p. 849.



Dimension, in.	T-Thickness, in.					Tolerances, in.
	¼ in. or under		Over ¼ to ½ in., incl.		Over ½ to 1 in., incl.[b]	
	Type I	Type II[c]	Type I	Type II[c]	Type I	
C—Width overall	0.750	0.750	1.125	1.125	1.500	±0.016
W—Width of flat section[a]	0.500	0.250	0.750	0.375	1.000	−0.000 +0.005
F—Length of flat section	2.25	2.25	2.25	2.25	2.25	±0.016
G—Gage length[d]	2.00	2.00	2.00	2.00	2.00	±0.016
D—Distance between grips[d]	4½	5¼	4½	5¼	5¼	±⅛
L—Length overall	8½	9⅜	9¾	10⅛	12	minimum

[a] Width, W, of the gage section shall be no larger at the center than at the ends and may be smaller at the center by as much as 0.004 in., as shown. If such a reduction is made it shall be gradual, suitably on a 210 in. minimum radius, equally on each side so that no abrupt changes in dimension result.

[b] Thickness, T, shall be 0.125 ± 0.015 in. for molded specimens and for other specimens where possible. If specimens are machined from sheets or plates, thickness, T, may be the thickness of the sheet or plate provided this does not exceed 1 in. For sheets of nominal thickness greater than 1 in. the specimens shall be machined to 1.000 ± 0.010 in. in thickness. For sheets of nominal thickness between 1 and 2 in. approximately equal amounts shall be machined from each surface. For thicker sheets both surfaces of the specimen shall be machined and the location of the specimen with reference to the original thickness of the sheet, shall be noted. Tolerances on thickness less than 1 in. shall be those standard for the grade of material tested.

[c] Type 1 specimens shall be used whenever possible. Type 2 specimens shall be used only for materials with which the Type 1 specimen does not give satisfactory breaks in gage length, such as resin-impregnated compressed laminated wood.

[d] Test marks only.

FIG. 1.—Tension Test Specimens for Sheet and Plate, Molded Plastics.

values of cross-sectional area so determined. Plugs shall be used in testing tube specimens as shown in Fig. 2.

In Paragraph (*c*) change the second and third sentences to read as follows: "There shall be allowed 0.25 in. between the ends of the gripping surfaces and the shoulders of the fillet of the flat test specimen; thus, the ends of the gripping surfaces should be 4.5 in. apart, as shown in Fig. 1, at the start of the test. The location for the grips on rod and tube specimens shall be as shown in Figs. 2 and 3."

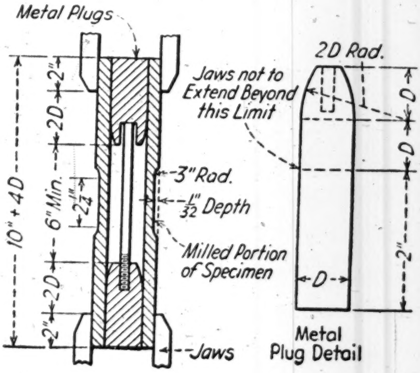


FIG. 2.—Tension Test Specimens for Tubes.

Tentative Method of Test for Haze of Transparent Plastics by Photoelectric Cell (D 672 - 42 T):

Section 3.—Change the first sentence to read as follows by the addition of the italicized words: "The apparatus shall consist of a haze meter as illustrated in Fig. 1 *or its optical equivalent.*"

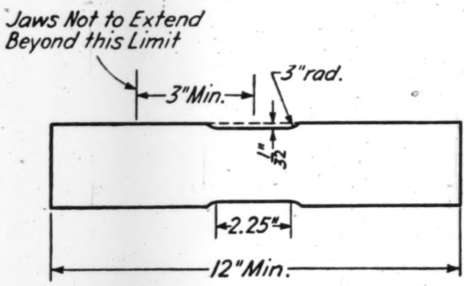


FIG. 3.—Tension Test Specimens for Rods.

Tentative Methods of Conditioning Plastics and Electrical Insulating Materials for Testing (D 618 – 41 T):

Section 4 (a).—Change the procedure for type *S* materials to read as follows:

> (*a*) *Type S Materials.*—Type *S* specimens shall be conditioned for a period of 48 hr. in the circulation air oven at a temperature of 50 ± 3 C. (122 ± 5.4 F.). The specimens shall be removed from the oven and cooled in the desiccator over anhydrous calcium chloride for a period of at least 3 hr. prior to actual testing. In the case of materials which are known or expected to require substantial time to attain essential stability of the property being measured, the cooling period shall be at least 16 hr. A definite time interval, previously decided upon by the cooperating laboratories, shall be allowed to elapse between the removal of the specimens from the desiccator and the application of the tests. The tests may be made at room atmospheric conditions.

REPORT OF COMMITTEE E-1

ON

METHODS OF TESTING

Although Committee E-1 on Methods of Testing held no meetings during the year, a number of its technical committees and sections have been active as noted later in this report.

The Executive Committee of the Society appointed three representatives-at-large to serve on the Advisory Committee, namely, E. P. Partridge, Hall Laboratories, Inc., A. J. Phillips, American Smelting and Refining Co., and Mr. L. J. Trostel, General Refractories Co., each for a three-year term, expiring in 1946.

Subsequent to the 1943 Annual Meeting, Committee E-1 presented to the Society through Committee E-10 on Standards the following recommendations:

New Tentative:

Hardness Conversion Tables for Steel (Relationship Between Diamond Pyramid Hardness, Rockwell Hardness, and Brinell Hardness) (E 48 – 43 T), and

Revision of Tentative Specifications for:

A.S.T.M. Thermometers (E 1 – 44 T), comprising requirements for six new solvents distillation thermometers.

The first recommendation was accepted[1] by Committee E-10 on August 24, 1943, and the second one was accepted[1] on March 15, 1944. The new tentative standard appears in the 1943 Supplement to Book of A.S.T.M. Standards, Part I, and the revised tentative specifications for thermometers will appear in the 1944 Book of A.S.T.M. Standards, Parts II and III.

ADOPTION OF TENTATIVE STANDARD AS STANDARD

The committee recommends that the specifications for the Air-Chamber Thermometer and for the A.S.T.M. Tung Thermometer prescribed in the Tentative Specifications for A.S.T.M. Thermometers (E 1 – 44 T) be approved for reference to the letter ballot of the Society for adoption as standard.

This recommendation has been submitted to letter ballot of the committee which consists of 56 voting members; 45 members returned their ballots, of whom 22 have voted affirmatively, 1 negatively, and 22 marked their ballots "not voting."

ACTIVITIES OF TECHNICAL COMMITTEES

Technical Committee I on Mechanical Testing (H. F. Moore, chairman):

War conditions have made the holding of special section meetings extremely difficult, and conditions of war production have, in general, made it undesirable to change standards unless a change was very urgently needed. These two factors account for the very small amount of activity in the sections of the Technical Committee on Mechanical Testing.

Section on Tension Testing (R. L. Templin, chairman).—This section has during the year received some criticisms of the details of standard tension specimens, and a criticism of the determination of the yield strength as applied to tension tests. These criticisms have been referred back to their authors with a request for detailed suggestions for changes, and such suggesions have not yet been received. This section has scheduled a meeting to be held during the 1944 annual Meeting.

---

[1] In submitting these recommendations to Committee E-10 on Standards, Committee E-1 reported the following results of the letter ballot vote from a committee membership of 55: E 48, 48 ballots returned, affirmative 33, negative 1, ballots marked "not voting" 14; E 1, 43 ballots returned, affirmative 31, negative 1, ballots marked "not voting" 11.

Section on Indentation Hardness (J. R. Townsend, chairman).—This section prepared the Tentative Hardness Conversion Tables for Steel (Relationship Between Diamond Pyramid Hardness, Rockwell Hardness, and Brinell Hardness (E 48 - 43 T) issued during the year, as mentioned earlier in this report.

An informal meeting held during the Metals Congress in Chicago, Ill., on October 19, 1943, was arranged by Mr. R. L. Kenyon of members of this section and representatives of the Society of Automotive Engineers and American Society for Metals to consider extending the hardness conversion tables to the lower ranges. It was the recommendation of this meeting that a paper be prepared covering the available data and discussing the conversion problems for the softer materials. There is accordingly being presented at this annual meeting a paper by Mr. R. H. Heyer on "Factors Affecting Hardness Relationships in the Range 50 to 250 Brinell."[2] The data presented in this paper will be further considered by the committee at a meeting to be held during the Annual Meeting.

Section on Flexure Testing (H. F. Clemmer, chairman).—This section has endeavored to secure papers on flexure testing, but, owing to pressure of war work, the authors of the papers have not been able to get them ready for presentation at this Annual Meeting.

Section on Effect of Speed of Testing (P. G. McVetty, chairman).—While this section has not held a meeting during the year, it is hoped that in the not distant future steps can be taken toward correlating the divergent requirements for speed of testing now found in A.S.T.M. Standards and Tentative Standards.

The other four sections of the Technical Committee on Mechanical Testing have been inactive during the past year. In two cases this has been on account of the pressure of war work, but in the other two very little discussion or criticism has come up to demand attention. Probably this lack of criticism may also be assigned to pressure of war work as a cause.

Technical Committee II on Consistency, Plasticity, and Related Properties (Eugene C. Bingham, chairman):

The work of this technical committee has been carried on by its several sections as noted below.

Information is being obtained by C. E. Kinney on the use of an air bath in place of the water or glycerin bath now required in the Tentative Method of Test for Softening Point (Ball and Shouldered Ring Apparatus) (E 28 - 42 T) since experience with the method in the testing of rosins has shown some variation in results for materials having softening points in the change-over range around 80 C. (176 F.). It is accordingly recommended that Method E 28 be continued as tentative.

Section on Industrial Flow Tests (Robert Burns, chairman).—This section will present a final report at a meeting of the technical committee to be held during this annual meeting on the studies conducted at Brooklyn Polytechnic Institute on the ring-and-ball softening point test.

Section on Use of Saybolt Furol Viscosimeter for Asphaltic Materials at High Temperatures (J. C. Geniesse, chairman).

---

[2] See p. 1027.

—This section has under study viscosity tests of asphaltic materials at high temperatures and it is expected that a report on this matter will be available within the coming year.

Section on Methods and Apparatus for Absolute Viscosity Measurements (W. F. Fair, Jr., chairman).—At a meeting of this section held during the year an outline was prepared of available methods for determining absolute viscosity. It is planned to compile the available information for future publication so as to make readily available a digest which would cover a classification of the various viscosimeters, a detailed description of the specific absolute viscosimeters, and a discussion of the use and applications of the various methods. Emphasis will be on the practical side and prime consideration will be given to instruments which are readily obtainable or readily assembled and which measure the consistency in absolute units.

Section on Definitions (R. N. Traxler, chairman).—This section has reviewed certain comments on the Standard Definitions of Terms Relating to Rheological Properties of Matter (E 24 – 42) received from Committee E-8 on Nomenclature and Definitions and will report on them at the June meeting.

Technical Committee III on Particle Size and Shape (L. T. Work, chairman):

The test program on measurement of particle size by microscopic methods has been delayed because of the war. The committee desires to await the completion of these studies before making any revision in the Tentative Method of Test for the Particle Size Distribution of Subseive Size Particulate Substances (E 20 – 33 T) and it accordingly recommends that the method be continued as tentative.

Technical Committee IX on Interpretation and Presentation of Data (H. F. Dodge, chairman):

The emphasis placed on quality control as a result of expanded production brought about by the war has accelerated the use of statistical methods. In this activity the A.S.T.M. Manual on Presentation of Data has been widely used in the many studies undertaken in the interest of improving the quality of products. The manual has also been used in a number of courses on application of statistics to industrial quality control sponsored by the Office of Research and Development, of the War Production Board.

Technical Committee X on Conditioning and Weathering (Robert Burns, chairman):

This technical committee has continued its cooperative work with other standing committees in considering questions relating to weathering and conditioning procedures prescribed in A.S.T.M. standards. No changes are recommended at this time in the Tentative Definitions with Procedures Relating to Conditioning and Weathering (E 41 – 42 T) and the Tentative Recommended Practice for Characteristics of Standard Carbon Arc Accelerated Weathering Unit (E 42 – 42 T), which are accordingly recommended for continuation as tentative.

Technical Committee XI on Designation and Interpretation of Numerical Requirements (J. A. Gann, chairman):

The Tentative Recommended Practices for Designation of Numerical Requirements in Standards (E 29 – 40 T), prepared by this technical committee, is being continued as tentative until several matters now under consideration have been completed. These deal with a recommendation on expressions to be used in connection with tolerances or permissible variations and the question as to what constitutes a reasonable deviation when the required precision does not contain an exact statement of permissible variations.

Technical Committee XII on Laboratory Apparatus (W. H. Fulweiler, chairman):

The sections of this technical committee have assisted other standing committees in reviewing recommendations for laboratory apparatus.

Section A on Thermometers (R. M. Wilhelm, chairman).—This section completed early in the year specifications for six new solvents distillation thermometers which had been requested by Committee D-1 on Paint, Varnish, Lacquer and Related Products. These were issued as tentative and incorporated in the Tentative Specifications for A.S.T.M. Thermometers (E 1 – 44 T), as mentioned earlier in this report.

Technical Committee XIII on Hydrogen Ion Determinations (E. B. Ashcraft, chairman):

This technical committee is sponsoring a round table discussion on hydrogen ion determinations to be held at this Annual Meeting. At this session a paper will be presented by Mr. G. G. Manov on "The pH of Some Standard Buffer Solutions from 0 to 60 C. and the Calibration of Glass Electrode pH Meters."[3] Mr. Manov will present a brief review of the fundamental theory of such measurements and will describe the methods used at the Bureau of Standards to measure the pK of acids and the pH of buffer solution; also the calibration of glass electrode pH meters.

The present officers of the committee have been re-elected for the ensuing term of two years.

Respectfully submitted on behalf of the committee,

W. H. FULWEILER,
Chairman.

P. J. SMITH,
Ex-officio Secretary.

---

[3] To be published in ASTM BULLETIN.

EDITORIAL NOTE

Subsequent to the Annual Meeting, Committee E-1 presented to the Society through Committee E-10 on Standards a proposed emergency alternate provision applying to the low cloud and pour test thermometers in the Standard Specifications for A.S.T.M. Thermometers (E 1 – 44). This recommendation was accepted by the Standards Committee on November 9, 1944, and the emergency provision appears in the 1944 Book of A.S.T.M. Standards, Part II and Part III, under the designation EA – E 1.

REPORT OF COMMITTEE E-2
ON
SPECTROGRAPHIC ANALYSIS

A meeting of Committee E-2 on Spectrographic Analysis was held on June 29, 1943, in Pittsburgh, Pa.

Nine new members were added to the committee during the year, bringing the total membership to 84.

Subsequent to the 1943 Annual Meeting, Committee E-2 presented to the Society through Committee E-10 on Standards the following recommendations:

New Tentative Methods of:

Spectrochemical Analysis of Lead Alloys for Impurities (E 49 - 43 T),
Spectrochemical Analysis of Tin Alloys for Impurities (E 51 - 43 T),

Revision of Tentative Methods of:

Quantitative Spectrochemical Analysis of Zinc for Lead, Iron, and Cadmium (E 26 - 35 T), and
Quantitative Spectrochemical Analysis of Zinc Alloy Die Castings for Minor Constituents and Impurities (E 27 - 40 T).

These recommendations were accepted[1] by Committee E-10 on August 30, 1943, and the new and revised tentative methods have been published as 1943 Supplements to A.S.T.M. Methods of Chemical Analysis of Metals.

A Report on "Standard Samples for Spectrographic Analysis" has been revised and edited by W. R. Brode and B. F. Scribner for publication by the A.S.T.M.[2]

Subcommittee III on Quantitative Methods and Applications (M. L. Fuller, chairman) has been active through its groups as follows:

Group 1 on Copper, Nickel and, Their Alloys (P. A. Leichtle, chairman) held a meeting in June, 1943, and several special meetings were held during the year. A high-voltage a-c. arc method for the analysis of nickel for manganese, silicon, magnesium, and iron is in preparation. A cooperative analytical test of a manganese-bronze sample was successfully completed. The group found that there is no single method applicable to the analyses of brasses and bronzes. There are several well established methods, however, and at least one of these will be ready for presentation this year.

Group 2 on Lead, Tin, Antimony, Bismuth, and Their Alloys (B. F. Scribner, chairman) met in June, 1943, at which time consideration was given to the preparation of a method alternate to the Tentative Methods of Spectrochemical Analysis of Tin Alloys for Impurities (E 51 - 43 T) and a revision of the Tentative Method of Quantitative Spectrochemical Analysis of High Grade Pig Lead (E 25 - 37 T).

Group 3 on Aluminum, Magnesium, and Their Alloys (H. V. Churchill, chairman) met in June, 1943, at which time the successful use of spectrographic analysis for aluminum and magnesium was discussed. Plans were made to write these industrial methods for consideration as A.S.T.M. standards.

---

[1] In submitting these recommendations to Committee E-10 on Standards, Committee E-2 reported the following results of the letter ballot vote from a committee membership of 71: E 49 and E 51, 46 ballots returned, affirmative 31, negative 0, ballots marked "not voting" 15; E 26, 54 ballots returned, affirmative 40, negative 1, ballots marked "not voting" 13; E 27, 54 ballots returned, affirmative 43, negative 0, ballots marked "not voting" 11.

[2] Issued as separate publication, 1944.

Group 4 on Zinc, Cadmium and Their Alloys (M. L. Fuller, chairman) held a meeting in June, 1943, at which it was decided to publish the method for the analysis of cadmium as a recommended practice. A spark excitation method for the analysis of zinc is now undergoing tests among members of the group.

Group 5 on Ferrous Metals (P. R. Irish, chairman) met in June, 1943. A survey of spectrographic practice in the ferrous industry has been completed. This showed a wide variation in details of the procedures used and it will be necessary to settle some points of difference before a standard method can be developed.

Group 6 on Nonmetals (R. H. Bell, chairman) held its first meeting in June, 1943. The group is engaged in making a survey of the methods and applications of spectrography to nonmetallic substances.

Subcommittee IV on Nomenclature and Definitions (J. J. Stumm, chairman) is preparing definitions of several important spectroscopic terms.

Subcommittee V on Standards and Pure Materials (T. A. Wright, chairman) held a meeting in June, 1943, at which requirements for standards were discussed. Considerable correspondence on standards was handled by the subcommittee.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, H. V. Churchill.
Vice-Chairman, T. A. Wright.
Secretary, Mary E. Warga.

This report has been submitted to letter ballot of the committee which consists of 84 members; 65 members returned their ballots, of whom 62 have voted affirmatively, and 0 negatively.

Respectfully submitted on behalf of the committee,

H. V. CHURCHILL,
Chairman.

B. F. SCRIBNER,
Secretary.

REPORT OF COMMITTEE E-3
ON
CHEMICAL ANALYSIS OF METALS

Committee E-3 on Chemical Analysis of Metals held one meeting during the year in Pittsburgh, Pa., on June 29, 1943. Five division and 12 subcommittee meetings were also held during the year.

Five new members were elected during the year, and one resignation accepted, bringing the total membership of the committee to 79.

A new edition of the A.S.T.M. Methods of Chemical Analysis of Metals was published in August, 1943. This edition contains 17 standard and tentative methods of chemical analysis comprising methods for the analysis of irons, steels, ferro-alloys copper-base alloys, aluminum and magnesium alloys, zinc, nickel, nickel alloys, pig lead, silver solders, lead-base alloys, and tin-base alloys. There is also included a section on spectrochemical methods for pig lead, zinc, and zinc-alloy die castings prepared by Committee E-2 on Spectrographic Analysis.

Very commendatory reviews of this publication have appeared, and reflect credit to the extensive work of many of the committee members. This sort of work is, however, never completed, and the committee is actively at work on a revision planned for 1945.

ACTIVITIES OF DIVISIONS AND SUBCOMMITTEES

Division A on Ferrous Metals (Arba Thomas, chairman).—A method for the determination of sulfur in steels by combustion has been prepared and will be submitted to the Society for publication as tentative. Work is being continued on methods for the determination of aluminum, tin, and boron.

Division B on Non-Ferrous Metals (D. R. Evans, chairman).—A joint committee of Committee E-2 on Spectrographic Analysis and Committee E-3 organized and directed a Symposium on Analytical Colorimetry and Photometry,[1] comprising some 20 papers, to which two sessions of the Annual Meeting of the Society are devoted.

Subcommittee B-1 on Copper and Its Alloys (R. P. Nevers, chairman) is continuing its work on the preparation of methods for special brasses and bronzes and has started work on methods for copper-nickel alloys of high-copper content.

Subcommittee B-2 on Lead, Tin, Antimony, Bismuth, and Their Alloys (C. A. Ray, chairman) has prepared and is now testing methods for the analysis of soft solders and bearing metal alloys.

Subcommittee B-5 on Precious Metals (R. H. Leach, chairman) has prepared several samples of silver solders for use in the testing of revised methods for such alloys.

Subcommittee B-7 (Clarence Zischkau, chairman) has been organized to cover Absorptiometric Procedures. An informal symposium on colorimetric procedures was held in October, 1943, and the committee is collecting and reviewing methods for further study.

---

[1] See pp. 709 to 778.

Division D on General Analytical Methods (B. L. Clarke, chairman).—This division has reviewed methods for the determination of sulfur by combustion submitted by Division A.

The following committee officers were elected for the ensuing term of two years:

Chairman, G. E. F. Lundell.
Vice-Chairman, C. B. Francis.
Vice-Chairman, H. A. Bright.
Secretary, J. W. Stillman.

This report has been submitted to letter ballot of the committee which consists of 79 members; 51 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

G. E. F. LUNDELL,
Chairman.

H. A. BRIGHT,
Secretary.

REPORT OF COMMITTEE E-4
ON
METALLOGRAPHY

Committee E-4 on Metallography has not met during the year, but several of its subcommittees were in session during the Spring Group Meetings of the Society, held in Cincinnati, Ohio, during the week of February 28, 1944.

The committee has gained several new members during the year, the total membership at this time being 71.

REVISION OF TENTATIVE STANDARDS

The committee recommends that the following tentative standards be revised as proposed by Subcommittee I and Subcommittee IV, respectively:

Tentative Methods of:

Preparation of Metallographic Specimens (E 3 - 42 T),[1] and
Preparation of Micrographs of Metals and Alloys (Including Recommended Practice for Photography as Applied to Metallography) (E 2 - 39 T).[1]

These recommendations were approved by letter ballot vote as follows: From a membership of 71, 54 members returned their ballots, 42 of whom voted affirmatively, 0 negatively, and 12 members marked their ballots "not voting" with respect to Methods E 3 - 42 T, and 52 members voted affirmatively, 0 negatively, and 9 members marked their ballots "not voting" with respect to Methods E 2 - 39 T.

ACTIVITIES OF SUBCOMMITTEES

Subcommittee I on Selection and Preparation of Samples (G. F. Comstock, chairman).—The subcommittee has been particularly active, having prepared the proposed revisions[2] in the Tentative Methods of Preparation of Metallographic Specimens (E 3 - 42 T) being recommended this year. Particular attention was paid to the incorporation of the latest and best recommendations pertaining to the more recent practices in electrolytic polishing.

A paper by P. F. George on "A Numerical Rating Method for the Routine Metallographic Examination of Commercial Magnesium Alloys,"[3] which deals specifically with the preparation of magnesium samples, will be presented at this Annual Meeting of the Society.

Subcommittee IV on Photography (L. V. Foster, chairman).—The Tentative Methods of Preparation of Micrographs of Metals and Alloys (Including Recommended Practice for Photography as Applied to Metallography) (E 2 - 39 T) have been reviewed in detail and a number of changes, more compatible with modern practice and equipment, have been incorporated in the proposed revised methods.[4] The changes include the deletion of Section 4 (*c*) referring to the form of the micrograph as submitted for publication, the omission of Table I covering recommended magnifications for various metals, the addition of a footnote to the section on grain size indicating that a minimum of 50 grains shall be measured, the omission of the power of the ocular to be used in securing standard magnifications in Table III, and the addition of a reference to amplifiers as an appropriate ocular for use when magnifications are 250 or higher, also changing the temperature at which development should take place from 65 F. to 68 F.

---

[1] 1942 Book of A.S.T.M. Standards, Part I.

[2] See p. 525.

[3] ASTM BULLETIN, No. 129, August, 1944, p. 35.

[4] The revised methods were accepted as tentative by the Society and appear in the 1944 Book of A.S.T.M. Standards, Part I.

In addition, the committee sponsored a technical paper by R. P. Loveland, Eastman Kodak Co., on "Metallography in Color," presented to the Society two years ago, which has now been revised by the author to include the most recent developments in photographs and color printing. The revised paper, with color plates, appears in ASTM BULLETIN, No. 128, May, 1944, p. 19.

Subcommittee VI on X-ray Methods (W. L. Fink, chairman).—The principal activities of this subcommittee have been concerned with the work on powder analysis of the Joint Committee on Chemical Analysis by X-ray Diffraction Methods, and a working agreement has been reached whereby an appreciable amount of foreign data will be available for new reference data. Several proposed recommended practices are nearing completion and it is expected that they will be ready for consideration during the year.

Subcommittee VIII on Grain Size (M. A. Grossman, chairman).—The several phases of grain size determination remain essentially as they have been during the past year. The Tentative Classification of Austenite Grain Size in Steels (E 19 – 39 T) is still proving eminently satisfactory, and no changes have been suggested or considered. The recommendations for the determination of ferritic grain size have been under consideration by the responsible subgroup, but because of the necessity for an appreciable amount of preliminary laboratory work this effort has been retarded by the pressure of present circumstances.

The grain size standard for non-ferrous metals (E 2 – 39 T) has been permitted to remain under the jurisdiction of Subcommittee IV pending the possibility of recommendations from Committee B-5 on Copper and Copper Alloys as a result of the interlaboratory tests which have been under way for some time. No action is contemplated at the present time.

Subcommittee IX on Inclusions (Samuel Epstein, chairman).—The Tentative Recommended Practice for Determining Inclusion Content of Steel (E 45 – 42 T) has apparently been proving satisfactory, inasmuch as no changes have been suggested. Consequently it is recommended that it be continued as tentative without revision.

The election of officers for the ensuing term of two years was held at the June meeting of the committee, as prescribed in its by-laws and resulted in the selection of the following:

Chairman, L. L. Wyman.
Vice-Chairman, R. E. Penrod.
Secretary, J. J. Bowman.

This report has been submitted to letter ballot of the committee which consists of 71 members; 45 members returned their ballots, all of whom voted affirmatively.

Respectfully submitted on behalf of the committee,

L. L. WYMAN,
Chairman

J. J. BOWMAN,
Secretary.

APPENDIX

PROPOSED REVISIONS IN TENTATIVE METHODS OF PREPARATION OF METALLOGRAPHIC SPECIMENS (E 3 - 42 T)[1,2]

Section 5.—In line 6, change "shall" to read "should."

Section 6.—In the second paragraph under the heading "Cast and Cement-Like Mountings," omit the last eleven lines starting with the words "These disadvantages of sulfur may be . . .".

Section 9.—Change the third paragraph to read as follows:

The wiring diagram shown in Fig. 3 is used with orthophosphoric acid as the electrolyte. The potential across the cell may be varied between 1 and 50 v. The glass beaker or dish of suitable size and shape forming the cell is placed beneath a stand holding a motor stirrer. The cathode is a stainless steel dish or sheet containing many perforations to permit suitable circulation of the electrolyte. Water flows through the resistor into the copper-alloy electrolyte-cooling tank and overflows into a rinsing bath. This apparatus should be assembled in a permanent fashion with all parts insulated or protected except those to be placed in the solution.

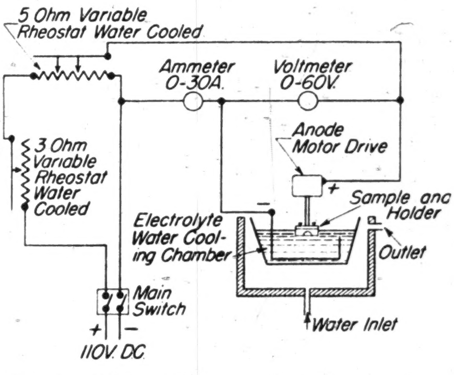

5 Ohm Variable
Rheostat Water Cooled
Ammeter
0-30A.
Voltmeter
0-60V.
Anode
Motor Drive
3 Ohm
Variable
Rheostat
Water
Cooled
+
−
Sample and
Holder
Electrolyte
Water Cool-
ing Chamber
Outlet
Main
Switch
+
−
Water Inlet
110V. DC

FIG. 3.—Wiring Diagram—Rotating Anode.

Section 10.—In line 5, change "four" to read "three."

Omit Part (*1*) entirely.

Change Part (*2*) to read as follows:

(*1*) *Steel.*—The electrolyte for polishing plain carbon and alloy steels is prepared by mixing glacial acetic acid and perchloric acid (65 per cent) in the proportions of 10 parts acetic to 1 part perchloric (Note). There is no explosion hazard attendant on mixing these acids, and no appreciable heating takes place.

The arrangement of Fig. 2, or a similar apparatus may be used. Since heating is not excessive during the polishing operation, the cooling bath may be omitted unless many specimens are to be polished consecutively.

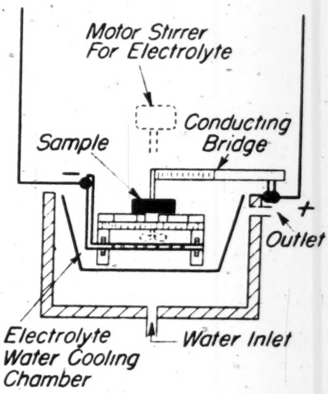

Motor Stirrer
For Electrolyte
Conducting
Bridge
Sample
−
+
Outlet
Electrolyte
Water Cooling
Chamber
Water Inlet

FIG. 3a.—Stationary Anode Equipment.

For satisfactory polishing, the resistance and distance from the sample to cathode are adjusted to give a voltmeter reading of 40 to 70 v. and an amperage of 1 to 2 amp., or a current density of 3 to 6 amp. per sq. dm. Unless the entire specimen is to be polished, connection may be made by means of an ordinary battery clip with the specimen only partially immersed. The surface to be polished should be roughly parallel to the cathode surface.

The time of polishing varies with the sample

---

[1] For explanation of this recommendation see p. 523.
[2] 1942 Book of A.S.T.M. Standards, Part I.

and its preliminary preparation. If the specimen is previously finished to No. 00 abrasive paper, the final electrolytic polish may take as long as 1 min. However, if the specimen is first given a complete metallographic polish, the time for electrolytic polishing is less than 15 sec., stirring is unnecessary, and surface undulations are avoided.

Staining and etching from the bath are minimized if the specimen is removed while the current is on, and is immediately placed in a dilute sodium hydroxide solution to neutralize the acids. The specimen may then be washed and dried in the usual manner.

Exhaustion of the polishing solution is indicated when the voltage drops below about 40 v. with a corresponding increase in amperage. A satisfactory polish may be obtained with a solution temperature from 15 to at least 40 C. The higher temperature range may give better results with stainless-type alloys.

NOTE.—Successful results with many varieties of steel specimens are also reported with a solution containing as little as 4 parts glacial acetic acid to 1 part perchloric acid, used after solution of about 0.5 per cent of iron or aluminum from dummy anodes and aging for 24 hr. The voltage recommended with this solution is 27 to 33 v. and the temperature should be kept below 85 F. With specimens of 0.1 to 1.0 sq. in. area, the anode and cathode should be 3.5 to 2.5 in. apart. With specimens ground with No. 1, 0, or 00 emery paper, and agitated while in the solution, the time required for polishing is reported to be 1.5 to 4 min.

Change the number of Part (*3*) to read "(*2*)" and insert the following paragraph immediately after the title:

For commercial aluminum alloys, the results from electrolytic polishing depend upon the type of micro-constituents present. Some constituents are dissolved rapidly; others are not dissolved at all during the electrolytic polishing process. In heterogeneous alloys, therefore, some of the constituents may be dissolved out entirely; others may be left standing in relief. This prohibits, in some instances, the use of electrolytic polishing methods for some cast and wrought aluminum alloys.

Change Part (*4*) to read as follows:

(*3*) *Copper and Copper-Zinc Alloys*.—Specimens cut on a saw may be filed, or ground on a belt grinder with 180 grit cloth, to obtain a reasonably smooth surface. The specimens thus prepared are placed on or in a non conducting stationary or rotating support and immersed in dilute orthophosphoric acid electrolyte with electrical connections as shown in Fig. 3. The time and voltage necessary to polish and etch the specimen vary with the concentration of the electrolyte. For polishing, the time required also depends upon the smoothness of the surface of the specimen. The anode current density ranges from about 5 to 20 amp. per sq. in. and the voltage from about 15 to 35 v. for the polishing operation. The time ranges from about 30 sec. to 2 min. depending upon the surface roughness of the original specimen.

Etching may be accomplished without removing the specimen from the electrolyte; simply adjust the variable resistor to give from 2 to 8 v.

The essential range of concentration of orthophosphoric acid is indicated in the following table:

	Deg., Baumé	Specific Gravity at 20/4 C.	Percentage H_3PO_4
Minimum	3.5	1.025	5
Maximum	10.3	1.075	14
Preferred	5.8	1.042	8

The approximate range of time and voltage employed for copper and for four alloys shown in the following table:

	Polishing Range, v.	Preferred		Etching Range, v.	Preferred	
		Volts	Time, sec.		Volts	Time, sec.
Cartridge brass	20-35	30	60	3 to 8	5	15
Free-cutting brass	20-35	25	45	2 to 5	3	10
Admiralty metal	20-35	25	60	3 to 6	5	15
Copper	15-30	20	45	1 to 4	3	10
Gilding	15-35	25	60	6 to 8	7	7

The arrangement advisable for the rotating anode is shown in Fig. 3. This equipment was designed for use with samples of uniform size and shape such as sections of cartridge case cups, tubes, etc. The cathode is a perforated stainless steel dish with connecting strip. The anode consists of a cloth-laminated plastic block machined to form four recesses for sample insertion, stainless steel springs and rods to secure samples and conduct current thereto from the rod which enters the chuck of the motor stirrer. The current is passed through the housing of the motor to the chuck and thence to the samples. The samples are rotated at slow speed in the electrolyte during the polishing and etching operations.

A cathode and anode suitable for use in polishing and etching samples of irregular size and shape are shown in Fig. 3, wherein the anode is stationary. The cathode (Fig. 4) consists of a perforated sheet of stainless steel with connecting strip mounted on four phenolite legs. A cloth-laminated plastic skeleton platform or bridge is fastened on top of the stainless steel. Two specimens are placed on the bridge forming the anode. A glass paddle is placed in the center to agitate the electrolyte and a wooden connector (Fig. 4) is wired internally to carry the current from a contact embedded in the table top to the anode (samples).

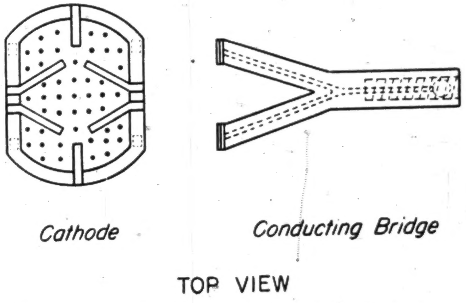


FIG. 4.—Conducting Bridge and Cathode for Stationary Anode.

Although specimens appear to polish and etch satisfactorily in the more concentrated solutions of orthophosphoric acid, many minute blemishes are discovered when specimens are examined under the microscope. Dilutions of the electrolyte and agitation thereof bring about a reduction of the number and the size of the blemishes.

A rough surface requires a longer time of electropolishing to remove the saw marks and to produce a surface suitable for etching. If, however, the specimen is ground on emery cloth or on a belt having about 180 grit, the electro-polishing time is cut to about 60 sec.

The extent of the contrast produced during the etching operation is governed by the time employed: specimens suitable for examination at higher magnifications require a shorter etching time. From 5 to 20 sec. usually are sufficient.

Table II.—Add the following data at the bottom of this Table:

Section 14.—Change the last sentence to read as follows:

> Some very interesting series of photomicrographs have been published in connection with (**6**) the diagram given in Fig. 5, and (**123**) the microstructure of 24S alloy.

Tables III, IV, V, VI, VII, IX, X, XI, and XII.—Change the footnote reference after the heading "Composition" from "3" to "4" and repeat footnote "4," as given for Table II, under each of these tables.

Section 23.—Change the second column, second line to read as follows: ". . . deep etching (15 per cent H_2SO_4 works . . . ."

In line 20, insert after ". . . purchased (46)." The following sentence "A detailed description of this method as applied to the macroscopic determination is given in the Tentative Recommended Practice for Determining The Inclusion Content of Steel (A.S.T.M. Designation: E 45)."[2]

Section 24.—At the end of this section add the following paragraph:

> The polishing of cast iron specimens in which graphite is to be studied, and of steel specimens to be studied in the etched condition, should usually not be considered finished until the specimens have been etched and repolished a number of times to remove the surface layers that have been disturbed by the previous stages of polishing (**51**). Care may be required to avoid pitting of inclusions, however, if this process is repeated too often. Recommended procedures for polishing microsections of cast iron have been described in detail in several publications (**82, 124, 125**).

Section 25.—At the end of this section add to the last sentence the following: "and two other recommended methods are given in the Tentative Recommended Practice for Determining the Inclusion

Etching Reagent	Composition	Remarks	Use
No. 10 Bossert's etch.	NaOH . . . . 1 g. Na_2CO_3 . . . . 1 g. Water . . . . 94 ml. Add to this solution 4 ml. of a solution containing 0.5 per cent each of $ZnCl_2$ and $SnCl_2$	Immerse specimen for 3 to 5 min. until etched surface becomes coated with heavy black deposit. Remove deposit by immersion in concentrated nitric acid. Wash with water.	This method is used for revealing the microstructures of the hard rolled and annealed tempers of duralumin-type alloys (**123**).

TABLE VII.—ETCHING REAGENTS FOR MAGNESIUM AND ITS ALLOYS.

Etching Reagent	Composition	Remarks	Use
No. 1. Acetic Acid	10 per cent aqueous solution	Swab with cotton for ½ to 3 min.	Macroetching.
No. 2. Tartaric Acid	10 per cent aqueous solution	Immerse polished face up.	Macroetching flowlines in forgings.
No. 3. Acetic-picral	6 per cent picric acid in 95 per cent ethanol ..... 100 ml. Glacial acetic acid ..... 10 ml.	Immerse polished face up. Make etchant up fresh just before using.	Macroetching for grain size in solution heat treated castings. Microetching for A.S.T.M. No. 18X sheet alloy.
No. 4. Glycol etchant	Ethylene or diethylene glycol ..... 75 parts by vol. Distilled water ..... 24 parts by vol. Concentrated HNO_3 ..... 1 part by vol.	See text	General etchant, excellent for alloys in the aged condition.
No. 5. Acetic-glycol	Ethylene or diethylene glycol ..... 60 parts by vol. Distilled water ..... 19 parts by vol. Glacial acetic acid .. 20 parts by vol. Concentrated HNO_3 ..... 1 part by vol.	Swab with cotton or immerse 2 to 15 sec.	All wrought alloys and solution heat treated cast alloys. Also good for Mg-Mn alloys.
No. 6. Phospho-picral	Ethyl alcohol (95 per cent). 100 ml. Picric acid ..... 4 g. Orthophosphoric acid ..... 0.7 ml.	Immerse face up until stained.	For extreme contrast between compounds and solid solution.

TABLE VIII.—MICROSCOPIC IDENTIFICATION OF CONSTITUENTS IN SAND-CAST MAGNESIUM ALLOYS.

Element	Detection		Unetched		Etched with Glycol-Etchant	
	Optimum Condition	Approximate Minutes, per cent	Shape	Color	Shape	Color
Al ($Mg_{17}Al_{12}$)						
massive	Etched	2.0	....	....	Filigreed network[b]	White
precipitated	Etched	....	....	....	Lamellar or fine particles.	Appears dark at low power.
Zn ($MgZn_2$)						
massive	Etched	1.5	....	....	Filigreed network[b]	White
precipitated	Etched	....	....	....	Fine particles	Appears dark at low power.
(Mg-Al-Zn)						
massive	Etched	2.0	....	....	Massive[b]	White
precipitated	Etched	....	....	....	Lamellars or fine particles	Appears dark at low power.
Mn	Unetched or etched	.... 0.5	[d] Angular	Bluish Gray	Angular	Bluish-gray
Cd[a]	....	....	....	....	......	......
Si (Mg_2Si)	Unetched or etched	0.03	Plates or script	Light blue	Angular plates or script	Blue
Sn (Mg_2Sn)	Etched	4.0	Network	Blue	Filigreed or massive network[e]	Brown, dark blue, purple
Cu (Mg_2Cu)	Etched	0.5	....	....	Globular or network[b, c]	White
Ni (Mg_2Ni)	Etched	0.5	....	....	Globular or network[b, c]	White

[a] Cadmium is completely soluble in solid magnesium and its alloys. No constituent visible under microscope. Coring generally visible when etched.

[b] Outlined.

[c] Depending on concentration.

[d] Mn constituent very hard and polishes in relief. Usually appears as pits at low magnification and particles are resolved at 250X or more.

[e] Usually shows coring around constituent.

Content of Steel (A.S.T.M. Designation: E 45).[2] An excellent discussion of inclusions in cast iron from the metallographic viewpoint has been published by Morrogh (125)."

Section 26.—In the third paragraph change last sentence to read as follows: "Alternate polishing and etching are very often required, especially for high-alloy steels, in order to obtain a correct development of the microstructure (**56, 98, 124**)."

Section 30.—Omit this section and substitute the following:

MAGNESIUM AND ITS ALLOYS. (63, 64, 131, 132, 133, 134)

30. *Preparation of Specimens.*—In general, the preparation of magnesium and magnesium alloy specimens is similar to the preparation of aluminum specimens. Sulfur or any of the plastic mounting materials can be used for mounting specimens too small to handle. Wood's metal or other metallic mounting materials should not be used because of galvanic attack at the point of contact when etched. The procedure described in the following paragraphs is recommended for developing the best results with magnesium but is not necessarily the only satisfactory method.

As in the preparation of aluminum specimens, a plane surface can be secured with a microtome; otherwise, grinding successively on aloxite cloths Nos. 50, 150, and 320 is recommended. The grinding is then finished by successive use of Nos. 0 and 000 metallographic emery paper. For convenience, the abrasive cloths or papers may be mounted on disks rotating at 800 to 1200 rpm. and the grnding on the No. 000 paper may be eliminated.

Polishing is carried out in two stages. The rough polishing is done on "Vel-chamee"[3] cloths mounted on disks rotating at 500 to 600 rpm. The abrasive used on this wheel is a distilled water suspension of No. 600 alundum. Only enough water is used to prevent seizure of the specimen. The fine polishing is accomplished on a velvet-covered or "Vel-chamee"[3] covered disk rotating at 100 and 400 rpm. and moistened with a suspension of specially levigated alumina (Note). Seizure is prevented by using a small amount of filtered liquid soap on the wheel. After polishing the specimen is rinsed in water, then in acetone or alcohol, and dried in a blast of warm air.

NOTE.—The specially levigated alumina recommended for fine polishing can be easily prepared by placing 150 g. of the best commercial levigated alumina and 2 liters of 0.001 N NaOH in a 4-l bottle and agitating (by a stream of compressed air) for 30 min. Two more liters of the 0.001 N NaOH are then added and the mixture shaken thoroughly. After standing 1½ hr., the upper ½ in. of supernatant liquor is carefully siphoned off, yielding the solution for fine polishing. Additional ½-in. portions may be taken 1½ hr. after each shaking.

Section 31.—Omit this Section and substitute the following:

31. *Etching Reagents.*—In Table VII are given the etching reagents commonly recommended for magnesium and its alloys.

NOTE.—The glycol etchant is suitable for almost all magnesium alloys in use today. Its virtue lies in its ability to reveal and outline the constituents without pitting or roughening. The technique of etching is as follows: Hold the specimen, polished face up, and immerse into the etchant with a sliding motion. Move the specimen back and forth during the time of immersion which will vary in time from 3 sec. on aged specimens to 1 min. on some solid solution alloys. Remove specimen and plunge in a stream of running water then in acetone or alcohol and dry in a blast of warm air.

Section 32.—Omit this Section and substitute the following:

32. *Examination and Identification of Constituents.*—As is suggested in the description of etchants (Table VII), visual or low-power macroexamination is usually made on specimens etched for ½ to 3 min. in reagents Nos. 1, 2 and 3. For such examination the etching is deep and the polishing need not be as carefully done as is necessary for microexamination, where etching is usually done in dilute acids and for short times in order to secure the necessary detail and avoid coring. Although the etchants shown in Table VII are the ones most commonly employed, numerous acids both organic and inorganic have been used with success. In all cases, etched specimens should be rinsed in running water, then in acetone or alcohol, and dried in a blast of warm air.

Table VIII outlines a method for identifying metallic constituents in sand cast materials when viewed through a microscope using an Eastman No. 78A filter. In the wrought alloys the identification differs slightly, chiefly because of the increased solubility of certain constituents and because of spheroidizing and breaking up of constituents by heat treating or plastic deformation. The table indicates the condition (etched or unetched) under which the constituent is best identified, the minimum amount which can readily be detected, and the usual appearance. Many of the constituents appear in a globular form when present in small amounts but take a network form when larger amounts are involved. This change may occur with a difference of a few tenths per cent for some of the elements, or it may require a change of as much as 10 per cent for development.

---

[3] This material available from John Ritzenthaler, 76 Franklin St., New York, N. Y.

Section 37.—Add the following at the end of this section:

The preparation of cross-sections of tinplate so as to show, with the microscope, the tin coating and its structure, requires very careful polishing and support of the edge of the specimen. Bakelite lacquer with cellophane has been found to afford satisfactory edge support, and polishing with alumina on broadcloth and velvet has given good results. (**129**)

Table XI.—Omit etching reagent No. 6, and substitute the following:

No. 6. Acid ferric chloride	$FeCl_3$ .... 2 g. HCl...... 5 ml. H_2O....... 30 ml. Ethyl Alcohol.... 60 ml.	Alternate polish and etch.	For block tin (**129**)
No. 7. Nitric and hydrofluoric acids in glycerine	HNO_3 .. 1 drop HF..... 2 drops Glycerine..... 25 ml.	Etch for 1 min. at 70 to 80 F.	For the tin coating on tinplate (**129**)

Change the present etching agent No. 7 to No. 8.

Table XII.—Add the following reagent for zinc and its alloys:

No. 4. Dilute (0.5 per cent) nitric acid (Nital). (**126**).	HNO_3 (Concentrated) .. 1 drop Alcohol (95 per cent)..... 10 ml. or HNO_3 (Concentrated)... 3 drops Amyl alcohol... 50 ml.	Apply like stronger Nital for etching steel. Should be used within one hr. after mixing.	For showing the zinc-iron alloys in galvanized steel or iron. (**127**), (**128**).

Section 39.—Add the following at the end of this section:

An improved method of preparation of specimens of galvanized iron or steel, involving the use of levigated alumina in water with a few drops of triethanol amine added to keep the pH value between 7 and 7.6, has been described and is recommended. (**128**)

References.—Add to reference (51) page number "170."

Add the following new references:

(**123**) F. Keller and R. A. Bossert, "Revealing the Microstructure of 24S Alloy," *Metal Progress*, January, 1942, P. 63.

(**124**) "Suggested Procedures for Polishing Microsections of Cast Iron," Appendix to Tentative Recommended Practice for Evaluating the Microstructure of Graphite in Gray Iron (A 247 – 41 T), 1942 Book of A.S.T.M. Standards, Part I, p. 1083.

(**125**) H. Morrogh, "The Metallography of Inclusions in Cast Iron and Pig Irons," *Journal*, Iron and Steel Inst., Vol. 143, No. 1, 207 P. (1941).

(**126**) W. Arthur and W. H. Walker, "Structure of Galvanized Iron," *Transactions*, Am. Inst. Metals, Vol. 6, p. 82 (1912).

(**127**) G. F. Comstock, "Mechanism of Peeling of a Zinc Coating," *Metal Progress*, August, 1937, p. 163.

(**128**) D. H. Rowland and O. E. Romig, "The Metallography of Galvanized Sheet Steel Using a Specially Prepared Polishing Medium with Controlled pH," *Transactions*, Am. Soc. Metals, Vol. 31, December, 1943, p. 980.

(**129**) Romig and Rowland, "Metallography of Tin and Tin Coatings on Steel," *Metals and Alloys*, Vol. 13, April, 1941, p. 436.

(**130**) I. A. Hauser, "Electrolytic Polishing of Metallographic Specimens," *Iron Age*, Vol. 153, January 20th, 1944, p. 48.

(**131**) H. B. Pulsifer, "Magnesium—Its Etching and Structure," *Transactions*, Am. Inst. Mining and Metallurgical Engrs., Vol. 78, p. 461 (1928).

(**132**) H. Vosskuhler, "The Technology of Magnesium and its Alloys," (1940). F. A. Hughes and Co., Abbey House, London, N. W. 1, England.

(**133**) J. B. Hess and P. F. George, "The Metallography of Commercial Magnesium Alloys," *Transactions*, Am. Soc. Metals, Vol. 31, p. 423 (1943).

(**134**) P. F. George, "A Metallographic Rating Method of Commercial Magnesium Alloys," *Preprint No.* 33, 1944. For 1944 Annual Meeting, Am. Soc. Testing Mats., New York, N. Y., June 26–30.

REPORT OF COMMITTEE E-8

ON

NOMENCLATURE AND DEFINITIONS

Committee E-8 on Nomenclature and Definitions held a meeting in Pittsburgh, Pa., on June 29, 1943, during the Annual Meeting of the Society.

The terms of M. E. Holmes and G. B. Waterhouse on the E-8 Advisory Committee expired last year. Mr. Waterhouse has been reappointed by the Executive Committee of the Society for a term of three years and J. W. McBurney of the National Bureau of Standards has been appointed as a new member.

The following definitions prepared by other commitees of the Society have been reviewed by Committee E-8 during the year:

Tentative Definitions of:

Terms "Magnetic Particle Method" and "Apparent Power" published as a tentative revision of the Standard Definitions of Terms, with Units and Symbols, Relating to Magnetic Testing (A 127 - 41), prepared by Committee A-6 on Magnetic Properties,

Terms "Askarel" and "Specific Gravity of Askarel," incorporated in the Proposed Methods of Testing Askarels, prepared by Committee D-9 on Electrical Insulating Materials,

Terms Relating to Textile Materials (D 123 - 43 T), prepared by Committee D-13 on Textile Materials,

Terms Relating to Soaps and Other Detergents (D 459 - 43 T), prepared by Committee D-12 on Soaps and Other Detergents,

Terms "Neutralization Number," "Strong-Acid Neutralization Number," "Base Neutralization Number," and "Strong-Base Neutralization Number," incorporated in the Tentative Method of Test for Neutralization Number of Petroleum Products by Color-Indicator Titration (D 633 - 42 T), prepared by Committee D-2 on Petroleum Products and Lubricants,

Terms "Fatigue," "Fatigue Stregth," "Mean Stress," and "Fatigue Ratio," incorporated in the Tentative Method of Test for Repeated Flexural Stress (Fatigue) of Plastics (D 671 - 42 T), prepared by Committee D-20 on Plastics, and

Term "Shear Strength," incorporated in the Tentative Method of Test for Shear Strength of Plastics (D 732 - 43 T), prepared by Committee D-20.

This review resulted in a number of comments and suggestions concerning the various definitions which have been brought to the attention of the responsible committees.

There has been increased interest on the part of a number of committees in establishing definitions for terms covering materials in their particular field of activity as is evidenced by the following new and revised definitions being presented to the Society at this Annual Meeting for publication as tentative:

Proposed Tentative Definitions of Terms, with Symbols, Relating to Magnetic Testing, prepared by Committee A-6 on Magnetic Properties,

Definition of "Air-Entraining Portland Cement," incorporated in the proposed revision of the Tentative Specifications for Air-Entraining Portland Cement for Concrete Pavements (C 175 - 42 T), prepared by Committee C-1 on Cement,

Proposed Tentative Symbols for Heat Transmission, prepared by Committee C-8 on Refractories,

Definition of "Daylight 45 deg., 0 deg. Apparent Reflectance," incorporated in the Proposed Tentative Method of Test for Daylight 45 Degree, 0 Degree Apparent Reflection of Paint Finishes," prepared by Committee D-1 on Paint, Varnish, Lacquer, and Related Products,

Definition of "Flaking," incorporated in the Proposed Tentative Method of Evaluating Degree of Flaking (Scaling) of Exterior Paints of the Linseed-Oil Type, prepared by Committee D-1,

Definition of "Bursting Strength," incorporated in the Proposed Tentative Method of Test for Bursting Strength of Paper, prepared by Committee D-6 on Paper and Paper Products,

Definition of "Water Vapor Permeability," incorporated in the Proposed Tentative Method of Test for Water Vapor Permeability of Paper and Paperboard, prepared by Committee D-6,

Proposed revision of the Tentative Definitions of Terms Relating to Soaps and Other Detergents (D 459 - 43 T), prepared by Committee D-12 on Soaps and Other Detergents, and

Proposed revision of the Tentative Definitions of Terms Relating to Textile Materials (D 123 - 43 T), prepared by Committee D-13 on Textile Materials.

In addition to the above, Committee D-13 is presenting to the Society at this Annual Meeting an extensive revision and rearrangement of the Standard Definitions of Terms Relating to Textile Materials (D 123 - 42). These revised definitions and those listed above will be reviewed by Committee E-8 during the year.

The report of Committee D-17 on Naval Stores, being submitted at this Annual Meeting, contains Proposed Definitions of Terms Relating to Tall Oil which will also be reviewed during the year.

Committee C-9 on Concrete and Concrete Aggregates is recommending for adoption as standard this year definitions of the following terms appearing in the Tentative Definitions of Terms Relating to Concrete and Concrete Aggregates (C 125 - 42 T): Blast-Furnace Slag, Crushed Gravel, Elongated Piece, Flat Piece, and Water-Cement Ratio. These definitions have been reviewed by the members of the E-8 Subcommittee on Sand and Aggregate (Cloyd M. Chapman, chairman). Suggestions concerning one or two of the definitions have been received and are being discussed with Committee C-9.

The election of officers for the ensuing term of two years resulted in the selection of the following:

Chairman, P. V. Faragher.
Vice-Chairman, R. P. Anderson.

This report has been submitted to letter ballot of the committee which consists of 50 members; 45 members returned their ballots, all of whom have voted affirmatively.

Respectfully submitted on behalf of the committee,

CLOYD M. CHAPMAN,
Chairman.

R. E. HESS,
Ex-officio Secretary.

REPORT OF COMMITTEE E-10 ON STANDARDS

As will be noted from this report, the number of recommendations submitted to Committee E-10 on Standards for action during the year was exceptionally large. In accordance with the emergency procedure[1] all recommendations covering the establishment of emergency alternate provisions to A.S.T.M. standards or complete emergency standards must be approved by Committee E-10. The standing committees also have submitted to Committee E-10 quite a few recommendations with respect to the publication of new tentative standards, revisions of tentative standards, or tentative revisions of standards.

Several emergency standards issued during the year have proved to be of permanent value and they are accordingly being recommended by the responsible standing committees for publication as tentative; in fact, some have already been changed from the emergency to regular status. Likewise some of the emergency provisions are being incorporated in the standards themselves rather than having them appear as emergency alternates.

Only one meeting of the committee was held during the year, much of its work having been handled by correspondence. At that meeting, held in Philadelphia, Pa., on August 30, 1943, H. S. Vassar was elected chairman of Committee E-10 to serve until June, 1944. The membership on Committee E-10 of J. R. Townsend and N. L. Mochel expired last year. The Executive Committee reappointed Mr. Mochel and appointed L. B. Jones of The Pennsylvania Railroad Co. to serve as members of Committee E-10 for a three-year term, expiring in 1946.

Review of A.S.T.M. Standardization Activities

A summary of new and revised tentative standards submitted at the 1943 Annual Meeting was included in the August issue of the ASTM Bulletin together with a review of standardization work of the various committees, with statements concerning new standards in prospect. Much of the information, particularly with respect to standardization projects under development in committees, is furnished by the standing committees subsequent to the Annual Meeting and takes advantage of the fact that many committees plan their next year's work at committee meetings held during the Annual Meeting.

At the present time, it is possible to make only a preliminary estimate, in terms of new and revised standards, of the volume of standardization work accomplished during the year which will be reported to the Society at this meeting. The reports of standing committees to be presented at the Annual Meeting include recommendations to the Society substantially as follows:

New standards	7
New tentative standards	54
Revisions of tentative standards	103
Tentative standards adopted as standards	70
Tentative revisions of standards	25
Revisions of standards recommended for adoption as standard	58
Standards and tentative standards withdrawn or replaced	9

---

[1] The complete emergency procedure is set forth in the 1943 A.S.T.M. Year Book, p. 356.

There are at present 738 standards and 435 tentative standards of the Society, making a total of 1173, and if the above recommendations are approved, this total will become 1223.

PROMOTION AND EXPANSION OF STANDARDIZATION ACTIVITIES

The already extensive field of activities of the Society, on the recommendation of Committee E-10, have been expanded by the formation of two new standing committees—on industrial aromatic hydrocarbons and metal powders and metal powder products—as authorized by the Executive Committee.

The Committee on Industrial Aromatic Hydrocarbons, which has been designated as Committee D-16, held its organization meeting on October 26, 1943, at which time the following scope of activities was agreed upon: "Nomenclature, methods of test, and specifications for industrial aromatic hydrocarbons and related products boiling below 400 F. for other than fuel purposes." J. M. Weiss, Consulting Chemical Engineer, was selected as temporary chairman, C. A. Lunn, Consolidated Edison Co., as temporary vice-chairman, and R. P. Anderson, American Petroleum Institute, as temporary secretary. An announcement with respect to the formation of this committee including the personnel and subcommittee structure appeared in the December, 1943, issue of the ASTM BULLETIN. Additional information is given in the report of the committee being presented to the Society at this Annual Meeting.[2]

As announced in the March, 1944, issue of the ASTM BULLETIN, Committee B-9 on Metal Powders and Metal Powder Products held its organization meeting on February 22, 1944, at which time W. A. Reich of General Electric Co. was elected chairman and W. R. Toeplitz of Bound Brook Oil-Less Bearing Co. was elected secretary. The following scope of activities was agreed upon: "The formulation of specifications and methods of test for metal powders and metal powder products." This committee is also reporting to the Society at this Annual Meeting.[3]

On the recommendation of Committee E-10, the Executive Committee has also authorized the appointment of a new standing committee on adhesives with the following scope: "The formulation of specifications, methods of test, and definitions of terms pertaining to adhesives, including animal, vegetable, mineral, and synthetic types." T. R. Truax of the U. S. Forest Products Laboratory is serving as temporary chairman to effect organization. It is expected that an organization meeting at Society Headquarters will be held shortly.

There have been no further developments with respect to the proposal that the Society undertake standardization work in the field of porcelain enamels.

CONSIDERATION OF NEW AND REVISED STANDARDS

Proposed new standards accepted by Committee E-10 and published as tentative during the year are as follows:

Tentative Specifications for:

Corrosion-Resisting Chromium Steel Clad Plate, Sheet, and Strip (A 263 – 43 T), submitted by Committee A-10 on Iron-Chromium, Iron-Chromium-Nickel and Related Alloys,

Corrosion-Resisting Chromium-Nickel Steel Clad Plate, Sheet, and Strip (A 264 – 43 T), submitted by Committee A-10,

Nickel and Nickel-Base Alloy Clad Steel Plate (A 265 – 43 T), submitted by Committee A-10,

Carbon-Steel Seamless Drum Forgings (A 266 – 43 T), submitted by Committee A-1 on Steel,

---

[2] See p. 490.

[3] See p. 292.

Copper Bus Bars, Rods, and Shapes (B 187 - 44 T), submitted by Committee B-5 on Copper and Copper Alloys, Cast and Wrought,

Copper Bus Pipes and Tubes (B 188 - 44 T) submitted by Committee B-5,

Red and Brown Iron Oxide Pigments (D 84 - 43 T), submitted by Committee D-1 on Paint, Varnish, Lacquer, and Related Products,

Methyl Ethyl Ketone (D 740 - 43 T), submitted by Committee D-1,

Nonrigid Vinyl Chloride-Acetate Plastics (D 742 - 43 T), submitted by Committee D-20 on Plastics,

Nonrigid Ethyl Cellulose Plastics (D 743 - 43 T), submitted by Committee D-20,

Nonrigid Vinyl Chloride Plastics (D 744 - 43 T), submitted by Committee D-20,

Nonrigid Vinyl Butyral Plastics (D 745 - 43 T), submitted by Committee D-20,

Natural Block Mica and Mica Films Suitable for Use in Fixed Mica-Dielectric Capacitors (D 748 - 43 T), submitted by Committee D-9 on Electrical Insulating Materials,

Chloroprene Sheath Compound for Electrical Insulated Cords and Cables (D 752 - 43 T), submitted by Committee D-11 on Rubber Products,

Chloroprene Sheath Compound for Electrical Insulated Cords and Cables Where Extreme Abrasion Resistance is Not Required (D 753 - 43 T), submitted by Committee D-11,

Insulated Wire and Cable: Heat-Resisting Synthetic Rubber Compound (D 754 - 43 T), submitted by Committee D-11,

Insulated Wire and Cable: Performance Synthetic Rubber Compound (D 755 - 43 T), submitted by Committee D-11,

Enclosures for Small Testing Machines for Tests at Subnormal and Supernormal Temperatures of Electrical Insulating Materials and Plastics (D 760 - 44 T), submitted jointly by Committee D-9 and Committee D-20,

Servicing Units for Tests at Subnormal and Supernormal Temperatures of Electrical Insulating Materials and Plastics (D 761 - 44 T), submitted jointly by Committee D-9 and Committee D-20,

Tentative Methods of:

Measuring Dimensions of Rigid Rods Used in Electrical Insulation (D 741 - 43 T), submitted by Committee D-9 on Electrical Insulating Materials,

Test for Brittleness of Nonrigid Plastics (D 746 - 43 T), submitted by Committee D-20 on Plastics,

Test for Stiffness in Flexure of Nonrigid Plastics (D 747 - 43 T), submitted by Committee D-20,

Calibrating a Light Source Used for Accelerating the Deterioration of Rubber (D 749 - 43 T), submitted by Committee D-11 on Rubber Products,

Test for Resistance to Accelerated Light Aging of Rubber Compounds (D 750 - 43 T), submitted by Committee D-11,

Testing Rubber-Coated Fabrics (D 751 - 43 T), submitted by Committee D-11,

Test for Resistance of Plastics to Accelerated Service Conditions (D 756 - 44 T), submitted by Committee D-20,

Test for Flammability of Plastics, Self-Extinguishing Type (D 757 - 44 T), submitted by Committee D-20,

Test for Tensile Strength and Compressive Strength of Plastics at Subnormal and Supernormal Temperatures (D 759 - 44 T), submitted by Committee D-20,

Spectrochemical Analysis of Lead Alloys for Impurities (E 49 - 43 T), submitted by Committee E-2 on Spectrograpic Analysis,

Spectrochemical Analysis of Tin Alloys for Impurities (E 51 - 43 T), submitted by Committee E-2,

Tentative Recommended Practice for:

Impact Strength Tests of Plastics at Subnormal and Supernormal Temperatures (D 758 - 44 T), submitted by Committee D-20 on Plastics, and

Tentative Hardness Conversion Tables for Steel (Relationship Between Diamond Pyramid Hardness, Rockwell Hardness, and Brinell Hardness) (E 48 - 43 T), submitted by Committee E-1 on Methods of Testing.

Revisions of the following tentative standards and tentative revisions of standards were accepted by Committee E-10 during the year:

Tentative Specifications for:

Iron and Steel Arc-Welding Electrodes (A 233 - 43 T), submitted by the Joint A.W.S.-A.S.T.M. Committee on Filler Metal,

Ready-Mixed Concrete (C 94 - 43 T), submitted by Committee C-9 on Concrete and Concrete Aggregates,

Orange Shellac and Other Lacs (D 237 - 43 T), submitted by Committee D-1 on Paint, Varnish, Lacquer, and Related Products,

Tar (D 490 - 43 T), submitted by Committee D-4 on Road and Paving Materials,

Polystyrene Molding Compounds (D 703 - 44 T), submitted by Committee D-20 on Plastics,

Cellulose Acetate Molding Compounds (D 706 - 43 T), submitted by Committee D-20,

Cellulose Acetate Butyrate Molding Compounds

(D 707 – 43 T), submitted by Committee D-20,

Vinylidene Chloride Molding Compounds (D 729 – 44 T), submitted by Committee D-20,

A.S.T.M. Thermometers (E 1 – 44 T), submitted by Committee E-1 on Methods of Testing,

Tentative Methods of:

Test for Permeability and Core Loss of Flat-Rolled Magnetic Materials Using 28-cm. Specimen (A 257 – 43 T), submitted by Committee A-6 on Magnetic Properties,

Test for Normal and Incremental Permeability and Core Loss of Flat-Rolled Magnetic Materials at Low Alternating Inductions Using 28-cm. Specimen (A 258 – 43 T), submitted by Committee A-6,

Test for Permeability of Feebly Magnetic Materials (A 259 – 43 T), submitted by Committee A-6,

Test for Impact Resistance of Plastics and Electrical Insulating Materials (D 256 – 43 T), submitted by Committee D-9 on Electrical Insulating Materials,

Chemical Analysis of Rubber Products (D 297 – 43 T), submitted by Committee D-11 on Rubber Products,

Test for Changes in Properties of Rubber and Rubber-Like Materials in Liquids (D 471 – 43 T), submitted by Committee D-11,

Testing Asphalt Composition Battery Containers (D 639 – 43 T), submitted by Committee D-11,

Test for Compressive Strength of Plastics (D 695 – 44 T), submitted by Committee D-20 on Plastics,

Testing Compressed Asbestos Sheet Packing (D 733 – 43 T), submitted by Committee D-11,

Quantitative Spectrochemical Analysis of Zinc for Lead, Iron, and Cadmium (E 26 – 43 T), Submitted by Committee E-2 on Spectrographic Analysis,

Quantitative Spectrochemical Analysis of Zinc-Alloy Die Castings for Minor Constituents and Impurities (E 27 – 43 T), submitted by Committee E-2,

Standard Specifications for:

Preformed Expansion Joint Fillers for Concrete (Nonextruding and Resilient Types) (D 544 – 41), submitted by Committee D-4 on Road and Paving Materials,

Standard Methods of:

Test for Magnetic Properties of Iron and Steel (A 34 – 42), submitted by Committee A-6 on Magnetic Properties,

Testing Sheet and Plate Materials Used in Electrical Insulation (D 229 – 43), submitted by Committee D-9,

Mechanical Analysis of Soils (D 422 – 39), submitted by Committee D-18 on Soils for Engineering Purposes,

Testing Pin-Type, Lime Glass Insulators (D 468 – 42), submitted by Committee D-9, and

Testing Preformed Expansion Joint Fillers for Concrete (Nonextruding and Resilient Types) (D 545 – 41), submitted by Committee D-4 on Road and Paving Materials.

Withdrawal of the Standard Specifications for Mineral Iron Oxide (D 84 – 41), recommended by Committee D-1 on Paint, Varnish, Lacquer, and Related Products, was also approved by Committee E-10.

ACTIONS UNDER EMERGENCY PROCEDURE

Emergency Alternate Provisions.—The emergency alternate provisions listed in Table I have been accepted by Committee E-10 during the year.

The withdrawal of the following emergency alternate provisions was approved by Committee E-10:

Designation	Emergency Alternate Provisions in *Standard Specifications for:*	Committee
EA – A 227	Hard-Drawn Steel Spring Wire (A 227 – 41)	A-1
EA – A 229	Oil-Tempered Steel Spring Wire (A 229 – 41)	A-1
EA – A 230	Carbon-Steel Valve Spring Quality Wire (A 230 – 41)	A-1

Emergency Standards.—Nine emergency standards have been accepted by Committee E-10 during the year as follows:

Emergency Specifications for:

Insulated Wire and Cable: Heat-Resisting Synthetic Rubber Compound (ES – 33), submitted by Committee D-11 on Rubber Products,

Insulated Wire and Cable: Performance Synthetic Rubber Compound (ES – 34), submitted by Committee D-11,

Controlled Quality, Magnesium-Base Alloy Die Castings (ES – 40), submitted by Committee B-6 on Die-Cast Metals and Alloys,

Emergency Methods of Test for:

Color of U. S. Army Motor Fuel (All Purpose) by Means of an A.S.T.M. Color Standard

TABLE I.—ACTIONS UNDER EMERGENCY PROCEDURE.

Designation	Emergency Alternate Provisions in	Committee
	Standard Specifications for:	
EA – A 30	Boiler and Firebox Steel for Locomotives (A 30 – 42)	A-1
EA – A 70a	Carbon-Steel Plates for Stationary Boilers and Other Pressure Vessels (A 70 – 42)	A-1
EA – A 89	Low Tensile Strength Carbon-Steel Plates of Flange and Firebox Qualities (A 89 – 43	A-1
EA – A 95	Carbon-Steel Castings for Valves, Flanges, and Fittings for High-Temperature Service (A 95 – 41)	A-1
EA – A 116	Zinc-Coated (Galvanized) Iron or Steel Farm-Field and Railroad Right-of-Way Wire Fencing (A 116 – 39)	A-5
EA – A 121	Zinc-Coated (Galvanized) Iron or Steel Barbed Wire (A 121 – 39)	A-5
EA – A 157	Alloy-Steel Castings for Valves, Flanges, and Fittings for Service at Temperatures from 750 to 1100 F. (A 157 – 42)	A-1
EA – A 167a	Corrosion-Resisting Chromium-Nickel Steel Plate, Sheet, and Strip (A 167 – 43)	A-10
EA – A 201	Carbon-Silicon Steel Plates of Ordinary Tensile Ranges for Fusion-Welded Boilers and Other Pressure Vssels (A 201 – 43)	A-1
EA – A 202	Chrome-Manganese-Silicon (CMS) Alloy-Steel Plates for Boilers and Other Pressure Vessels (A 202 39)	A-1
EA – A 203	Low-Carbon Nickel-Steel Plates for Boilers and Other Pressure Vessels (A 203 – 42)	A-1
EA – A 204	Molybdenum-Steel Plates for Boilers and Other Pressure Vessels (A 204 – 42)	A-1
EA – A 212	High Tensile Strength Carbon-Silicon Steel Plates for Boilers and Other Pressure Vessels (Plates 4½ in. and Under in Thickness) (A 212 – 39)	A-1
EA – A 214a	Electric-Resistance-Welded Steel Heat-Exchanger and Condenser Tubes (A 214 – 42)	A-1
EA – A 240a	Corrosion-Resisting Chromium and Chromium-Nickel Steel Plate, Sheet, an Strip for Fusion-Welded Unfired Pressure Vessels (A 240 – 43)	A-10
EA – B 16	Free-Cutting Brass Rod for Use in Screw Machines (B 16 – 42)	B-5
EA – B 60a	Castings of the Alloy: Copper 88 per cent, Tin 8 per cent, Zinc 4 per cent (B 60 – 41)	B-5
EA – B 61	Steam or Valve Bronze Castings (B 61–42)	B-5
EA – B 62a	Composition Brass or Ounce Metal Castings (B 62 – 41)	B-5
EA – B 86b	Zinc-Base Alloy Die Castings (B 86 – 43)	B-6
EA – D 69a	Friction Tape for General Use for Electrical Purposes (D 69 – 38)	D-11
EA – D 496a	Chip Soap (D 496 – 39)	D-12
EA – D 498a	Powdered Soap (Nonalkaline Soap Powder) (D 498 – 39)	D-12
	Tentative Specifications for:	
EA – A 158	Seamless Alloy-Steel Pipe for Service at Temperatures from 750 to 1100 F. (A 158 – 42 T)	A-1
EA – A 206	Seamless Carbon-Molybdenum Alloy-Steel Pipe for Service at Temperatures from 750 to 1000 F. (A 206 – 42 T)	A-1
EA – A 216a	Carbon-Steel Castings Suitable for Fusion Welding for Service at Temperatures up to 850 F. (A 216 – 42 T)	A-1
EA – B 22a	Bronze Castings for Turntables and Movable Bridges and for Bearing and Expansion Plates of Bridges (B 22 – 42 T)	B-5
EA – B 143a	Tin-Bronze and Leaded Tin-Bronze Sand Castings (B 143 – 42 T)	B-5
EA – B 144a	High-Leaded Tin-Bronze Sand Castings (B 144 – 42 T)	B-5
EA – B 145a	Leaded Red Brass and Leaded Semi Red Brass Sand Castings (B 145 – 42 T)	B-5
EA – B 146a	Leaded Yellow Brass Sand Castings for General Purposes (B 146 – 42 T)	B-5
EA – D 224a	Asphalt Roofing Surfaced with Powdered Talc or Mica (D 224 – 41 T)	D-8
EA – D 225	Asphalt Shingles Surfaced with Coarse Mineral Granules (D 225 – 41 T)	D-8
EA – D 249a	Asphalt Roofing Surfaced with Coarse Mineral Granules (D 249 – 42 T)	D-8
EA – D 574a	Insulated Wire and Cable. Ozone-Resistant Type Insulation (D 574 – 40 T)	D-11
	Standard Methods of:	
EA – D 129	Test for Sulfur in Petroleum Oils by Bomb Method (D 129 - 39)	D-2
EA - D 147	Testing Bituminous Mastics, Grouts, and Like Mixtures (D 147 – 41)	D-8
EA - D 231	Testing and Tolerances for Knit Goods (D 231 - 39)	D-13
	Tentative Methods of:	
EA – D 228	Testing Asphalt Roll Roofing, Cap Sheets, and Shingles (D 228 – 42 T)	D-8

(ES – 32), submitted by Committee D-2 on Petroleum Products and Lubricants,

Changes in Protective Properties of Organic Coatings on Steel Surfaces When Subjected to Immersion (ES – 35), submitted by Committee D-1 on Paint, Varnish, Lacquer, and Related Products,

Chlorine in Lubricating Oils by Bomb Method (ES – 36), submitted by Committee D-2,

Phosphorus in Lubricating Oils (ES – 37), submitted by Committee D-2,

Lead, Copper, and Iron in Lubricating Oils (ES – 38), submitted by Committee D-2, and

Metals in Lubricating Oil (ES – 39), submitted by Committee D-2.

Revisions of the following emergency specifications were accepted by Committee E-10:

Emergency Specifications for:

GR-S Synthetic Rubber Sheath Compound for Electrical Insulated Cords and Cables (ES – 6a), submitted by Committee D-11 on Rubber Products, and
Controlled Quality Aluminum-Base Alloy Pressure Molded Castings (ES – 29a), submitted by Committee B-6.

Committee E-10 approved the recommendation of Committee D-11 that the following emergency standards be withdrawn and issued as tentative:

Emergency Specifications for:

Chloroprene Sheath Compound for Electrical Insulated Cords and Cables (ES – 28) [replaced by Tentative Specifications D 752 – 43 T],
Chloroprene Sheath Compound for Electrical Insulated Cords and Cables Where Extreme Abrasion Resistance is Not Required (ES – 30) [replaced by Tentative Specifications D 753 – 43 T],
Insulated Wire and Cable: Heat-Resisting Synthetic Rubber Compound (ES – 33) [replaced by Tentative Specifications D 754 – 43 T], and
Insulated Wire and Cable: Performance Synthetic Rubber Compound (ES – 34) [replaced by Tentative Specifications D 755 – 43 T].

RELATIONS WITH THE AMERICAN STANDARDS ASSOCIATION

Revised Standards Submitted Under Proprietary Procedure.—The Society has been granted proprietary sponsorship for the revision of A.S.T.M. standards approved as American Standard under the existing standards procedure and, functioning as proprietary sponsor, has submitted to the American Standards Association during the year revisions of the following standards, all of which have been approved:

Standard Specifications for:

Low Tensile Strength Carbon-Steel Plates of Structural Quality for Welding (A 78 – 43; ASA G40.1-1943),
Low Tensile Strength Carbon-Steel Plates of Flange and Firebox Qualities (A 89 – 43; G30.1-1943),
Carbon-Silicon Steel Plates of Ordinary Tensile Ranges for Fusion-Welded Boilers and Other Pressure Vessels (A 201 – 43; G31.1-1943),
Electrolytic Copper Wire Bars, Cakes, Slabs, Billets, Ingots, and Ingot Bars (B 5 – 43; H17.2-1943),
Basic Carbonate White Lead (D 81 – 43; K23.1-1943),
Chrome Yellow and Chrome Orange (D 211–43; K27.1-1943), and

Standard Methods of:

Laboratory Sampling and Analysis of Coal and Coke (D 271 – 43; K18.1-1944).

Standards Submitted Under Sectional Committee Procedure.—Reports were received from three of the sectional committees for which the Society is sponsor submitting standards to the ASA for approval. These reports were transmitted to that association and the following standards have been approved for the first time or reapproved in revised form during the year as American Standard:

On the Recommendation of Sectional Committee C59 on Electrical Insulating Materials:

A.S.T.M. Methods of:

Testing Molded Materials Used for Electrical Insulation (D 48 – 43 T; ASA C59.1-1944),
Testing Electrical Insulating Oils (D 117 – 43; C59.2-1944),
Testing Sheet and Plate Materials Used in Electrical Insulation (D 229 – 43; C59.13-1944),
Test for Impact Resistance of Plastics and Electrical Insulating Materials (D 256 – 43 T; C59.11-1944),
Testing Laminated Tubes Used in Electrical Insulation (D 348 – 42; C59.14-1943),
Testing Laminated Round Rods Used in Electrical Insulation (D 349 – 42; C59.15-1943),
Testing Shellac Used for Electrical Insulation (D 411 – 42; C59.18-1944),

NEMA Laminated Phenolic Products Standards (C59.16-1944), and
NEMA Practice for Machining and Punching of Laminated Phenolic Plate (C59.17-1944).

On the Recommendation of Sectional Committee G8 on Specifications for Zinc Coating of Iron and Steel:

A.S.T.M. Specifications for:

Zinc-Coated (Galvanized) Iron or Steel Telephone and Telegraph Line Wire (A 111 – 43; ASA G8.3-1944),

Zinc-Coated (Galvanized) Iron or Steel Farm-Field and Railroad Right-of-Way Wire Fencing (A 116 – 39; G8.9-1944),
Zinc-Coated (Galvanized) Iron or Steel Barbed Wire (A 121 – 39; G8.10-1944), and
Zinc-Coated Steel Wire Strand (Class B and Class C Coatings) (A 218 – 41; G8.11-1944).

On the Recommendation of Sectional Committee Z11 on Petroleum Products and Lubricants:

A.S.T.M. Methods of:

Test for Vapor Pressure of Petroleum Products (Reid Method) (D 323 – 43; ASA Z11.44-1943),
Test for Carbonizable Substances in White Mineral Oil (Liquid Petrolatum) (D 565 – 43; Z11.49-1943),
Test for Dropping Point of Lubricating Grease (D 566 – 42; Z11.51-1943),
Test for Carbonizable Substances in Paraffin Wax (D 612 – 43; Z11.50-1943), and
A.S.T.M. Standard Viscosity-Temperature Charts for Liquid Petroleum Products (D 341 – 43; Z11.50-1943).

ASA WAR COMMITTEE ON RADIO TO BE DISBANDED

The War Committee on Radio which, as indicated in the 1943 report of Committee E-10, had been formed under the war standards procedure of the American Standards Association at the request of the War Production Board to set up war standards for components for military radio to help speed production of radio equipment for the Army and Navy, make replacements of parts easier, and conserve materials, is to be terminated, the work to be taken over by a joint Army-Navy group. At the time this project was initiated, the Armed Forces could not spare the personnel required to handle such a program. Since then, conditions have changed and the Army-Navy Electronics Standards Agency (ANESA) was established recently to take over this work. The War Committee on Radio had already completed fourteen standards which include a number of references to A.S.T.M. methods of testing. To avoid any substantial loss of effort already expended, those subjects which are nearly completed will be concluded under the war procedure of the ASA, and the remaining specifications will be handled exclusively by ANESA. In completing the work, ANESA will utilize the current ASA drafts of the specifications which they have started to develop. The existing ASA task groups which have been developing the standards will be disbanded, as ANESA will seek the cooperation of industry by other means.

Respectfully submitted on behalf of the committee,

H. S. VASSAR,
Chairman.

R. E. HESS,
Ex-officio Secretary.

TECHNICAL PAPERS

With Discussions

EDGAR MARBURG LECTURE

THE PURPOSE of the Edgar Marburg Lecture is to have described at the Annual Meetings of the American Society for Testing Materials, by leaders in their respective fields, outstanding developments in the promotion of knowledge of engineering materials. Established as a means of emphasizing the importance of promoting knowledge of materials, the Lecture honors and perpetuates the memory of Edgar Marburg, first Secretary of the Society.

TEXTILE FIBERS

AN ENGINEERING APPROACH TO THEIR PROPERTIES AND UTILIZATION[1]

NINETEENTH EDGAR MARBURG LECTURE

BY HAROLD DEWITT SMITH[2]

The engineering approach to the evaluation of textile fibers which is the central theme of this lecture was first discussed by the author in elementary form in an unpublished paper which was delivered before the Textile Executives' Club in Boston on February 13, 1940, and again, without publication, before the American Association of Textile Technologists in New York on November 6, 1940. This lecture embodies the first publication of an elaboration of these ideas.

INTRODUCTION

ON THE EVOLUTION OF TEXTILE THINKING

There is no such thing as a *natural textile fiber!* There are only *natural fibers* which have been selected by mankind for use in textiles.

The utility and the beauty of the textiles which man has created down the ages by the ingenious manipulation of selected natural fibers into yarns and fabrics bear witness to his skill. Textiles made of natural fibers serve a multiplicity of civilized purposes, ranging from the stark strength of a ship's hawser to the lustrous majesty of a royal robe or the diaphanous luxury of the sheerest lingerie.

The invention of textile structure by the twisting together of short fibers to form long yarns, and the interlacing of fibers or yarns to form supple, tough, porous sheets of material which we call *fabrics*, ranks with the utilization of fire and the invention of the wheel, of the lever, and of pottery, as one of the unique triumphs of the early human mind.

The natural fibers which man has chosen, and in many cases improved by careful breeding, in order to provide himself with raw materials for his varied textile needs were evolved by nature for diverse purposes, but in no instance for combining into textile yarns or for interlacing into textile fabrics. Some few members of the animal kingdom use natural fibers to build a structure, which in every case is rigid, and, therefore, lacking in that internal flexibility which is the very essence of the architecture of textiles. The caterpillar manufactures its own silken strand and winds it about itself to form a stiff shell or cocoon of cemented fibers within which to sleep and dream of the beautiful moth or butterfly it is to be. The bird gathers twigs, grass, feathers, and even condescends to borrow bits of yarns from man, to build its nest, a rigid structure in which to raise its young. The wasp is a paper maker which converts natural fibers into a multilayered crepe paper home in which to dwell securely.

---

[1] Read on June 28, 1944, before the Annual Meeting of the American Society for Testing Materials, New York, N. Y.

[2] Treasurer and Textile Technologist, The A. M. Tenney Associates, Inc., New York, N. Y.

Other animals utilize natural fibers less consciously, having been provided by nature with a furry or a woolly coat of hairs for protection against the elements. Early man undoubtedly used the pelts of fur-bearing animals for many purposes for which he subsequently invented textile fabrics. That these man-made "substitutes" for pelts were found to be superior to the natural product is proved by the fact that the human race now clothes itself with textiles rather than with sheepskins and fur pelts, except for two widely separated groups. One of these comprises Eskimos and other so-called primitive peoples whose environment makes it easier to get and prepare pelts than to raise and process natural fibers suitable for the types of textile garments required for such climates. The other group comprises femininity the world over, to whom the style appeal of a coat of carefully selected furs means much more than the mere matter of keeping warm.

The Armed Forces of the United States and its Allies, profiting by the fine work on cold-weather clothing which was one of the most valuable fruits of the several polar expeditions led by Admiral Byrd, have proved beyond a doubt that furs are the traditional clothing material of races which live in very cold climates *only* because furs are the best materials which have been available to such peoples.

The multilayered clothing of our Arctic forces, with its thin, dense, wind-resistant, water-repellent, but moisture-permeable outer layer over light, lofty inner layers of pile fabrics or other air-entrapping textile structures, has proved superior to traditional Arctic fur clothing. We can look for a change in Eskimo styles after the war when some of our Arctic troopers go back over the Alcan Highway with sample trunks of "warmth without weight" clothing instead of military packs and guns!

This development is one specific illustration of the thesis of my lecture, namely, that an engineering approach to the design and utilization of textile fibers, yarns, and fabrics is needed in order to blend textile craftsmanship with modern textile science if the textile industry is to exploit its opportunities and meet its obligations in the world of today and tomorrow.

To return to nature's uses of fibers, the vegetable kingdom, which provides man with the greatest tonnage and variety of natural fibers for textiles, evolved these fibers for several non-textile purposes. There are seed hairs, such as kapok and milkweed, designed by nature to waft the seeds afar, and cotton which is a hairy seed coat believed to have evolved as a protection against dehydration rather than as a seed parachute. The other two important types of vegetable fibers are bast fibers, which grow within the stalk, and leaf fibers. The natural function of both of these types is to form part of the skeletal structure of plants, and the fibers are cemented or chemically united to other plant constituents into a structure which, while more flexible than that of many homogeneous materials, is nevertheless not comparable with the suppleness achieved by man in textiles.

For man, directing the amazing manipulative skill of his hands by the even more amazing thinking mechanism of his brain, created textiles—structural forms of matter which are unique throughout the natural and the man-made universe because of the three very diverse but very valuable characteristics which they combine, namely, strength and toughness on the one hand, a very high degree of suppleness or flexibility on the other, and these two in a structure which is porous and permeable to air, to water vapor, and, if desired, even to light.

Not only for the purpose of this lecture, but in all our thinking about the structure and utilization of textiles, we should remember that *the essence of the textile invention is the building up of large, useful structures—threads, ropes, felts, nets, cloth—by combining countless tiny fibrous units in such ways that the individual strength and toughness of each fiber is accumulated, yet its individual freedom of movement and, hence, its suppleness, although restrained, is largely retained.*

Because of the organic nature of all natural fibers except asbestos (which, incidentally, was known to, and used by, the Greeks), archaeologists have found no textiles among the earliest evidences of man's works. Nevertheless, basket-like mold impressions on pottery, and stones which were evidently used as warp weights on primitive one-bar looms, provide evidence that weaving and, probably, spinning were well known to stone-age humans. One can imagine that vines and reeds were the first textile raw materials. Perhaps the search for more supple strands led to strips of leather and then to the furry and woolly hairs of animals on the one hand and, on the other, to the vegetable fibers through the observation that, although the dried stalks of some plants broke too easily to be good for even coarse weaving, a layer of tough, fine strands between the outer bark and the woody core remained unbroken and could be separated from the broken chaff and twisted into finer, softer yarns than the stalks of reeds or vines.

Textiles were undoubtedly first invented by prehistoric engineers for purposes such as ropes, snares, fish nets, containers, and shelters. However, the love of decoration and beauty which is evidenced by painted cave walls, by patterns on very ancient specimens of pottery, and by the painting of human bodies which is still practiced by many primitive races, must have caused the early artist, as well as the early engineer, to search for finer and finer fibers to use as textile raw materials and to develop increasing manipulative skill in combining these finer, more delicate fibers into textiles in which beauty of texture, of color, and of touch was added to the necessary comfort and utility for which they were produced.

The list of natural fibers currently available in commercial quantities (in times of peace) which the A.S.T.M. Committee D-13 on Textiles has compiled and published[3] provides evidence of the persistence with which man has searched for, and experimented with, natural fibers for textile purposes since the first human twisted several strands of vine together to make a rope. There are 15 animal fibers on this list, 3 mineral fibers, and 110 vegetable fibers. Of the vegetable fibers, 7 are classed as seed hairs, 35 as bast (stalk) fibers, 60 as leaf or leaf-stem fibers, and 8 miscellaneous. This list, totaling some 128 different natural fibers of commercial importance for textiles, may be accepted as the final "Report by Mankind" on a textile research project which started at least ten thousand years ago and encompassed the investigation of countless natural fibrous materials, for it is unlikely that there remains undiscovered any new natural fiber capable of achieving a very large measure of importance for textiles.

Within the lifetime of many of us who are here today, Mankind has initiated a second great textile research project, namely, the *creation of textile fibers.* This new research program is now motivated by an urge which is much more profound than the mere imitative impulse with which it started, namely, the urge to create new utility and new beauty.

---

[3] "List of Man-made and Natural Fibers," *Standards on Textile Materials*, Am. Soc. Testing Mats., p. 356 (1943). (Issued as separate publication.)

TABLE I.—WORLD PRODUCTION OF PRINCIPAL TEXTILE FIBERS—1938.

Fiber		From data supplied by Textile Unit, Bureau of Foreign and Domestic Commerce, U. S. Department of Commerce	From A.S.T.M. Standards on Textile Materials	
		Tons (2000 lb.)	Fiber Group	Principal Uses
Cotton		7 032 000	Seed hair	Industrial, household, and apparel textiles.
Jute		1 377 000	Stalk	Bagging, twine, and backing yarn in pile carpets.
Wools (clean basis)			Animal hairs	Apparel, household, and industrial textiles.
Apparel[a]	777 150			
Carpet	250 250			
Mohair	15 130			
Alpaca[b]	3 350			
Total Wool		1 046 000		
Rayons (all types)			Manufactured	Apparel, industrial, and household textiles.
Filament yarn	496 550			
Staple fiber	467 950			
Total Rayon		964 000		
Flax		880 000	Stalk	Household, apparel, and industrial textiles.
Asbestos (all types)[c]		484 000	Mineral	Industrial textiles, thermal insulation, and packing.
Hemp		415 000	Stalk	Twines, halyards, and tarred rigging.
Sisal		285 000	Leaf	Twines and coarse cordage.
Abaca (Manila "hemp")		169 000	Leaf	Ropes, coarse twines, and cordage.
Sunn "hemp"		110 000	Stalk	Twines.
Ramie[d]		110 000	Stalk	Woven textiles, tapestries, seine nets, shoe thread, and trimmings.
Coir[c]		90 000	Shell (cocoanut)	Door mats, and upholstery stuffing.
Henequen[a]		72 000	Leaf	Binder twine, coarse twine, and small ropes
Silk		55 000	Animal cocoon	Apparel, household, and industrial textiles.
Istle		42 000	Leaf	Brush bristles, and twines.
Kapok[f]		37 000	Seed hair	Stuffing in pillows, mattresses, and life preservers.
Cantala (Maguey)[e]		13 000	Leaf	Coarse twines.
Phormium		7 000	Leaf	Twines.
Total		13 188 000		

[a] 1939.
[b] Peru only (major producer). No figures available for Argentina, Bolivia, and Chile.
[c] Major producing countries included.
[d] Estimated for 1936. Latest available.
[e] Incomplete.
[f] 1941 exportable surplus of major producing countries. (Domestic consumption data not available.)
NOTE.—Data on following fibers not available from Department of Commerce: angora rabbit, camel hair, cashmere, chingma, horsehair, kenaf, mescal maguey, piteira, and wild silk.

An examination of the figures on world production of textile fibers reveals that, despite the large number of natural fibers listed as commercially available, the really important classes of natural fibers are few in number. For 1938, the last year in which a free exchange of economic data between nations was possible, the principal fibers for which production data are listed by the U. S. Department of Commerce[4] number 18, as shown in Table I. According to the glossary prepared by A.S.T.M. Committee D-13,[5] eight of these are used principally in fabric form for industrial, household, and apparel purposes, and the remaining ten for ropes, cordage, and twine, or for stuffing. The eight are, in the order of tonnage importance, cotton, jute, wool, rayon, flax, asbestos, ramie, and silk. Cotton is certainly king, accounting for over half of the total of thirteen million tons. Silk was a deposed queen even in the pre-war world, but a queen whose beauty and elegance should never be allowed to disappear completely from the textile scene. It is interesting to note that the rayons, within the half-century since Count Hilaire de Chardonnet started the first "artificial silk" factory in Belgium, had attained fourth place in world importance.

---

[4] Communication from Textile Unit, Bureau of Foreign and Domestic Commerce, Department of Commerce, June 23, 1944.

[5] "Glossary of Terms Relating to Textile Materials", *Standards on Textile Materials*, Am. Soc. Testing Mats., p. 346 (1943). (Issued as separate publication.)

If we analyze the long list of fibers in Committee D-13's previously mentioned "List of Man-made and Natural Fibers," we find that many of the individual fibers listed are merely different species of a few genii, or families, or are of local rather than of world importance, and that most of the various wool and hair fibers listed are closely related to one another in their chemical and morphological structure and, therefore, in their general chemical and physical behavior.

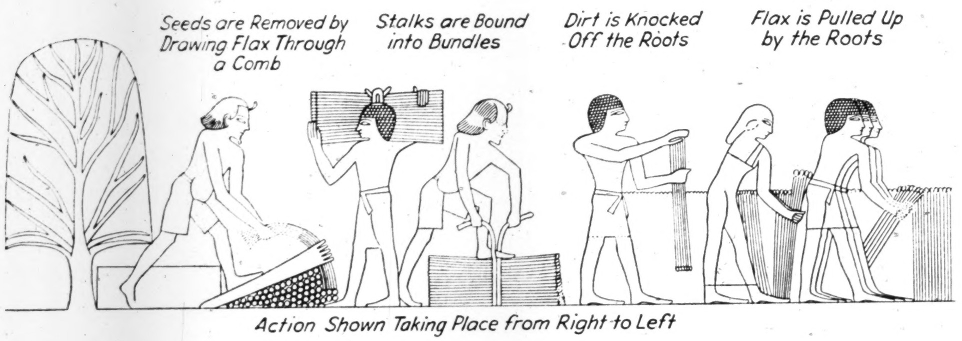
In other words, this first great textile research project which was initiated by our prehistoric ancestors in order to find fibers which could be spun into textile yarns yielded a group of hair fibers with the general characteristics of wool; a small group of continuous filament cocoon fibers with the general characteristics of silk; a group of vegetable seed hair fibers with the general characteristics of cotton; a group of "soft" bast or stem fibers with a range of general characteristics represented by flax, hemp, jute, and ramie, respectively; a group of "hard" leaf fibers with a range of general characteristics represented by abaca (Manila "hemp"), sisal, henequen, and phormium; and one group of mineral fibers with the general characteristics of asbestos.

This adds up to six fundamental types of spinnable, natural fibers, each distinctive with respect to its molecular and morphological architecture. These six types differ enough in textile qualities to stand out in our minds as six distinct and easily recognizable sensory evaluations of textile character which can be labeled with the subjective descriptive terms: wool-like, silk-like, cotton-like, linen-like, sisal-like, and asbestos-like These homely adjectives epitomize the long, exciting, and fruitful evolution of textiles up to the early part of the present century.

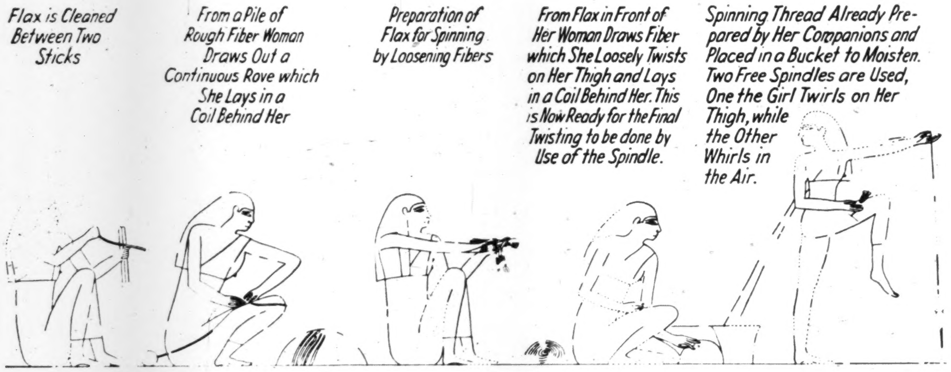
But they also emphasize, by their very connotation, that the thinking of textile craftsmen and of consumers of textiles has been inevitably fettered by ages of dependence upon a few types of fibrous substances whose fundamental properties and behavior have remained essentially unchanged, despite the generations of patient husbandry and careful breeding which have been devoted to their evolution and refinement.

The flax fibers in the oldest existing fabric, which was found in Egypt and dated approximately 7000 B.C., have the same chemical and morphological structure as those of present-day flax. Five thousand years later, the Egyptians left a record, in the form of paintings and bas-relief on the walls of various tombs, of the technology of flax harvesting, spinning, and weaving, as practiced during the period 2200 to 1500 B.C. (Fig. 1).

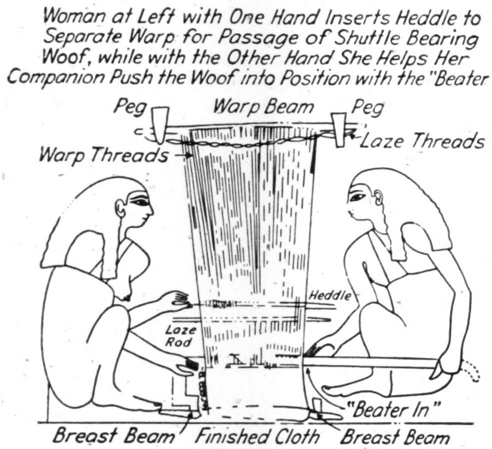
About two weeks ago, a native of the former Austro-Hungarian Empire described to me how flax was harvested, retted, hackled, spun, and woven on her father's farm when she was a girl. These thirty-five hundred year old Egyptian pictures are adequate illustrations of the techniques which she described, ex-


Seeds are Removed by Drawing Flax Through a Comb
Stalks are Bound into Bundles
Dirt is Knocked Off the Roots
Flax is Pulled Up by the Roots
Action Shown Taking Place from Right to Left

(*a*) Gathering flax in the field.


Flax is Cleaned Between Two Sticks
From a Pile of Rough Fiber Woman Draws Out a Continuous Rove which She Lays in a Coil Behind Her
Preparation of Flax for Spinning by Loosening Fibers
From Flax in Front of Her Woman Draws Fiber which She Loosely Twists on Her Thigh and Lays in a Coil Behind Her. This is Now Ready for the Final Twisting to be done by Use of the Spindle.
Spinning Thread Already Prepared by Her Companions and Placed in a Bucket to Moisten. Two Free Spindles are Used, One the Girl Twirls on Her Thigh, while the Other Whirls in the Air.

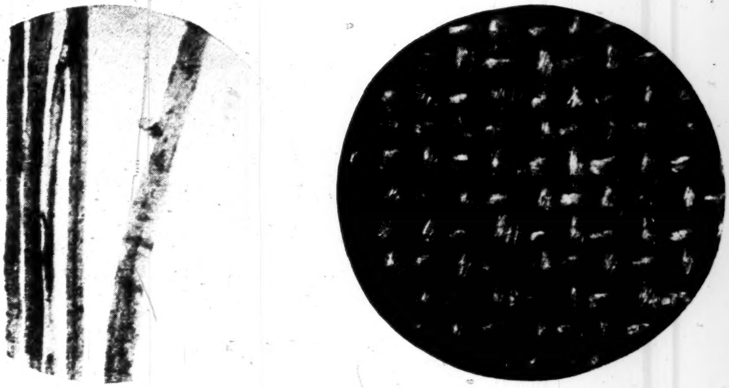
(*b*) Preparation and spinning of flax.


Woman at Left with One Hand Inserts Heddle to Separate Warp for Passage of Shuttle Bearing Woof, while with the Other Hand She Helps Her Companion Push the Woof into Position with the "Beater In"
Peg
Warp Beam
Peg
Warp Threads
Laze Threads
Heddle
Laze Rod
"Beater In"
Breast Beam
Finished Cloth
Breast Beam

(*c*) Weaving of flax on horizontal beam.

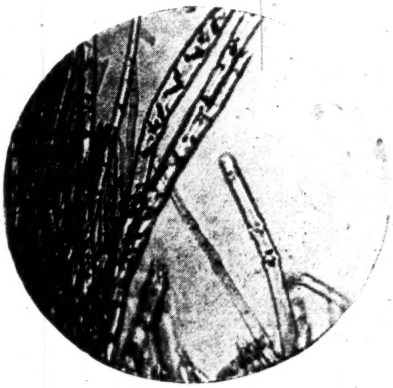
FIG. 1.—Flax Technology in Ancient Egypt (2200 to 1500 B.C.).

Courtesy of the Metropolitan Museum of Art

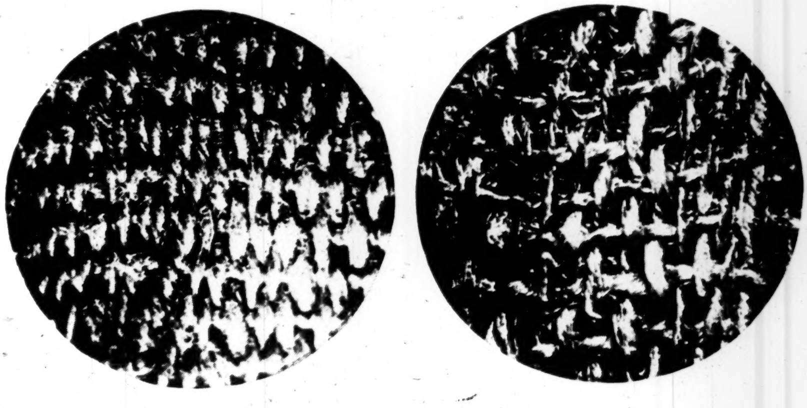


Modern flax fibers.

Modern linen fabric.



Ancient Egyptian flax fibers.



Ancient Egyptian linen fabrics.

FIG. 2.—Ancient and Modern Flax Fibers and Linen Fabrics.

Courtesy of the Metropolitan Museum of Art cept for the substitution of a spinning wheel for the simple spindle whorl and some purely mechanical improvements of the hand-loom.

Photomicrographs of fibers from Egyptian fabrics made during the period represented by these tomb paintings and of fibers from a present-day linen fabric indicate the unchanging nature of the structure of the flax fiber (Fig. 2).

The numerous present-day varieties of flax differ from one another chiefly in fineness and length and, therefore, to a degree in tactile and visual qualities such as softness and luster, but all are characterized by the smooth, cool feel, the high water absorbency, the tendency toward crispness, the lack of "give," which we integrate when we say that a fabric is *linen-like.*

TABLE II.—COMPARISON OF ANCIENT AND MODERN COTTON FIBERS.

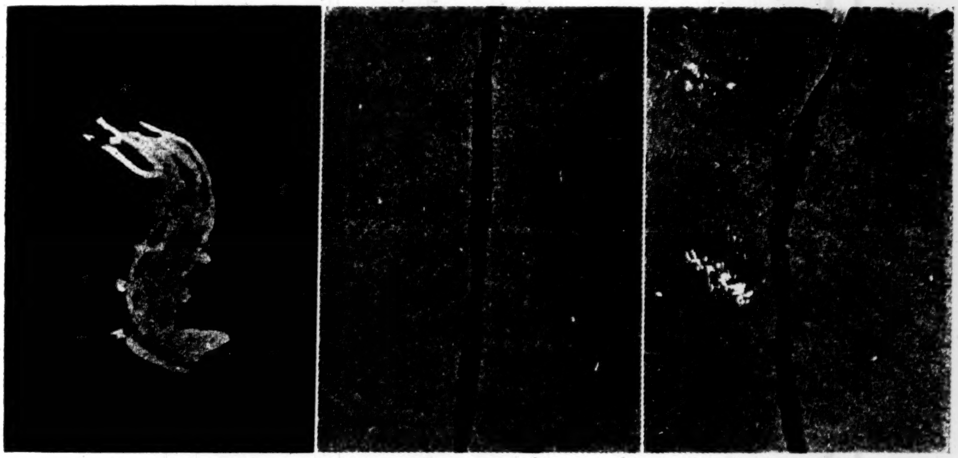
(Data on modern and ancient Indian cottons from A. N. Gulati and A. J. Turner, *The Journal of the Textile Institute,* Vol. 20, p. T-1 (1929).

	Modern Indian Cottons	Ancient Indian Cotton	Modern Long Staple Cottons	
			Sakel.	Sea Island
Origin	India	Excavations at Mohenjo-Daro Indus Valley, India	Egypt	West Indies
Date	1925 to 27 A.D.	3000 B.C.	1935 A.D.	
Fiber width, mm	0.014 to 0.023	0.020		
Fiber fineness, gx	2.29 to 3.77	3.17	1.2 to 1.5	0.9 to 1.2
Convolutions per inch	45 to 114	73		
Fiber strength, g. per gx	1.92 to 1.41	0.82	3.2 to 4.3	5.3

Both silk and wool have been bred for thousands of years as carefully as any strain of horseflesh or of prize cattle. In the case of silk, the result has been longer continuous lengths of fiber per cocoon, greater uniformity of fiber diameter from one end of the cocoon filament to the other, and a marked improvement in fineness as compared to the wild varieties. But when we examine the silk fibers in the earliest bits of silk textiles which were excavated in Central Asia (500 to 300 B.C.), we find that they have the same fibrous architecture as those which the well-bred, modern silkworm, *Bombyx mori,* spins today. This structure of the silk fiber is responsible for the smooth, luxurious feel, the bloomy luster, and the strength and durability which we imply by the term *silk-like.*

In the case of wool, breeding has increased the weight of wool per fleece, the length, the fineness, and the curl, or crimp, as compared to the undomesticated animal. But the fibers from the earliest shreds of wool cloth which were recovered from Scandinavian bog graves of the Bronze Age (3500 to 2500 B.C.) are built up of the same spindle-shaped cortical cells of keratin surrounded by the same shingle-like layer of epithelial scales as is a modern merino fiber, and this structure is responsible for the springiness, the felting power, the high elastic recovery, and the warm feel of fabrics which we describe as *wool-like.*

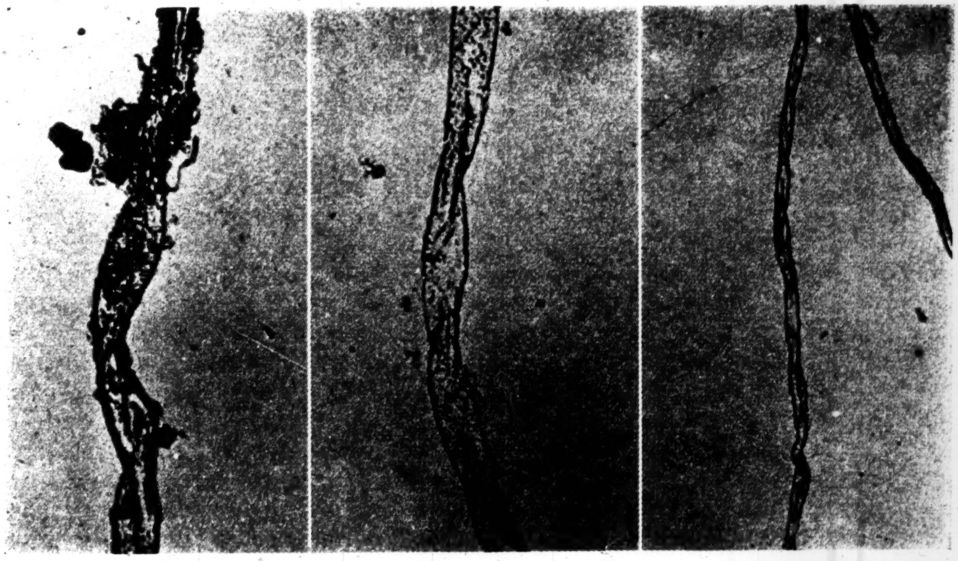
An examination of one of the earliest known fragments of cotton textiles reveals an analogous persistence of fiber structure. Breeding has produced longer, finer, and somewhat stronger cotton, but the cotton fibers from fragments of cloth and yarns found in the Indus Valley among relics which date back to about 3000 B.C., like the fibers in today's cotton fabrics, are flattened, twisted tubes, the walls of which are composed of fibrils of cellulose built up in a number of concentric layers—and the textile



(*a*) (*b*) (*c*)

(*a*) Cotton cloth fragment. Approximate construction: 2 oz. per sq. yd.; 60 × 20; warp and filling, 34/1.

(*b*) and (*c*) Cotton fibers from cloth fragment.



(*d*) (*e*) (*f*)

(*d*) and (*e*) Cotton fibers from a fragment of cord. The approximate construction of the cord is 14/6/2/2 making a total of 24 ply.

(*f*) Cotton fibers from a fragment of another cord. Approximate construction: 18/12/2 making a total of 24 ply.

FIG. 3.—Cotton Textiles Found at Mohenjo-Daro in the Indus Valley, India, dated between 3500 and 2700 B.C.

The Date Limits are Based on Seals and Other Objects found at the Same Site.
From A. N. Gulatti and A. J. Turner, "A Note on the Early History of Cotton," *Journal*, Textile Inst., Vol. 20, p. T-1, 1929.

character which we call *cotton-like* is the result of this unchangeable fibrous structure (Fig. 3 and Table II).

During the last twenty years of the nineteenth century and the first thirty years of this century, the blossoming of man's knowledge of the chemical and physical nature of things turned him toward the effort to *create* textile fibers in the image of silk. Silk was the obvious model because it was the most costly, the most beautiful, and, therefore, the most desirable of the natural fibers in the eyes of the textile consumer.

For almost the whole of that fifty-year period, the several man-made fibers which survived the experimental stage and emerged into the commercial world were called "artificial silks," a frank declaration of the motive which produced them and of the light in which they were viewed by the textile craftsman and the consumer. About twenty years ago, the producers and the merchants of these new members of the textile fiber family invented the generic term "rayon" to replace the term "artificial silk." This was an event of far greater significance to the textile world than the mere christening of a new group of fibers. It was a moment of historic textile importance because it first emphasized that these man-made fibers, despite any outward similarity to silk and despite the natural tendency to use them in imitation of silk, were actually new and destined to stand or fall on their own distinctive properties and values.

About ten years ago, another idea, which had been germinating since the early days of continuous filament rayon, namely, to cut these filaments into short lengths comparable to the staple lengths of cotton and of wool and to spin them into yarns on cotton, woolen, and worsted machinery, suddenly flowered into commercial success. The fabrics made of these spun rayon yarns were less like cotton, linen, woolen, worsted, or spun silk fabrics than were continuous filament rayons like silk fabrics. But textile thought was still too rigidly encased in the restrictions imposed by the natural fibers to think in any terms except those of comparison with the natural fibers. Hence, spun rayon fabrics were described as "woolly" or "worsted type" or "linen-like." The commercial advent of fibers made from milk casein in 1936 tended to perpetuate this comparative mode of thinking because they were first used to supplement the dwindling supply of wool in Axis countries and their identity was generally lost in blending with wool.

The next step in the invention of manufactured fibers widened the breach which the rayons had made in the walls of tradition surrounding the textile mind, and its fruition is even now crumbling the obstacles to objective thinking about textile fibers and letting in the light of a scientific and engineering approach.

This step was the synthesis of fibrous molecules out of elements and simple organic compounds and the building up of these molecules into fibers suitable for textiles. The Vinyon of 1938, the nylon of 1939, and the Saran of 1940 are undoubtedly only the forerunners of an increasing number of manufactured fibers whose varied "personalities," added to those of the rayons, will emancipate us from the old mode of thinking about textile fibers, fabrics, and machinery, thereby opening new vistas toward the achievement of mankind's insatiable desires for beauty, utility, and economy in the field of textiles.

ON THE EVALUATION OF TEXTILE FIBERS

Members of Committee D-13 are familiar with the microscopic appearance of the various natural and manufactured fibers but, for those whose interest and activities are centered on other structural materials, the photomicrographs of some of the more important fibers which are reproduced in Appendix D[6] may help to visualize these "microbeams" whose mechanical behavior we are about to examine. Since all of the exposures from which this series of photomicrographs were taken were made at a magnification of 500 diameters, they show not only the surface character and the cross-sectional shape of each fiber type, but also a comparison of the fineness of each.

A photomicrograph provides useful information about the surface character of a fiber and the size and shape of fiber cross-sections, but, because of the minute portion of the length of the fiber which is encompassed within the field of the microscope, it tells us nothing about two of the most important characteristics of fibers for textiles, namely, the length and the ratio of length to diameter.

Committee D-13 has defined the word "fiber," as follows:

"Fiber: 1. *General.*—The fundamental unit used in the fabrication of textile yarns and fabrics.

> 2. *Specific.*—A unit of matter characterized by having a length at least 100 times its diameter or width, and with the exception of noncrystalline glass fiber, having a definitely preferred orientation of its crystal unit cells with respect to a specific axis.
>
> 3. *Textile.*—Fibers that can be spun into a yarn or made into a fabric by interlacing in a variety of methods, including weaving, knitting, braiding, felting, and twisting."

A footnote states that the minimum fiber length which is practical for spinning into yarn is 5 mm. or about $\frac{1}{5}$ in. Such short fibers could only be spun in blends with longer "carrier" fibers. For cotton yarns, the minimum limit of length for spinnability is about $\frac{1}{2}$ in.

To visualize the significance of the ratio, $\frac{\text{length}}{\text{diameter}}$, imagine a model of a textile fiber made to a linear magnification of 200. The minimum fiber as defined by Committee D-13 would have a diameter of $\frac{1}{8}$ in. for a length of 12 in. A fiber of $\frac{1}{2}$ in. Bengal (Indian) cotton would have a diameter of $\frac{1}{8}$ in. and a length of $8\frac{1}{2}$ ft. A fiber of $1\frac{3}{4}$ in. Egyptian cotton would have a diameter of $\frac{1}{16}$ in. and a length of 27 ft. One has only to imagine the problem of untangling (without excessive breakage) a tangled mass of millions of flexible rods of these dimensions and of arranging them in a continuous strand of parallel rods whose ends overlap at random along the length of the strand, to gain a tremendous respect for the ingenuity of man's manipulative skill in converting masses of fibers into spun yarns and also to realize why so few of the many natural and manufactured materials which have, or might be given, the size and shape of a textile fiber possess the right balance of strength, suppleness, and toughness to meet the demands of processing and of serviceability.

As a guide to the actual dimensions of textile fibers, the approximate range of width or diameter and of length of a number of the important fibers is listed in Table III. In thinking of fiber dimensions it is well to remember that, whereas the range of diameter or fineness and the relation between fineness and length of each natural fiber is fixed by nature, the range of dimensions in which the manufactured fibers may be produced can be varied at will and extended in both directions.

In Table IV, I have listed the fundamental characteristics which determine the textile value of a fiber. The stature which a fiber attains in the textile world

---

[6] Appendix D—Photomicrographs of Common Textile Fibers is not included with the lecture in the *Proceedings*. These photomicrographs are part of the A.S.T.M. Tentative Methods for Identification of Fibers in Textiles (D 276 – 43 T), 1944 Book of A.S.T.M. Standards, Part III, p. 1939.

TABLE III.—APPROXIMATE DIMENSIONS AND FINENESS OF SOME TEXTILE FIBERS.

Fiber	Diameter or Width,[a] microns[c]			Length, Commercial Range, in.	Length/Diameter Ratio	Fineness, grex	
		Range	Mean or Most Commonly Used			Range	Mean or Most Commonly Used
Spider Silk	(d)		5	Continuous			
Glass	(d)	5.8 to 12.2	7	Any length staple and continuous		0.5 to 2.9	0.8
Saponified Acetate Rayon	(d)		8.2	Continuous			0.8
Cotton—Sea Island	(aw)	8.5 to 10	9.5	1⅝ to 2	5000	0.9 to 1.2	1.1
Silk—China	(aw)	10 to 11	10.5	Continuous			1.2
—Japan	(aw)	11 to 12.5	11.5	Continuous			1.4
Cupram. Rayon	(aw)	6.5 to 11.5	11	Continuous		0.5 to 1.6	1.5
Viscose Rayon—Staple	(aw)	8.3 to 43	11.8	Any desired length		0.8 to 22	1.7
—Filament	(aw)	9.7 to 37	12.5	Continuous		1.1 to 16	1.9
Fur Fibers—Various	(d)	11 to 16	13	½ to 3	800 to 7000	1.1 to 2.4	1.4
Vicuna	(d)	12.5 to 14.5	13.5	8	14000	1.6 to 2.2	1.9
Flax	(aw)	14 to 16	15[b]	12 to 36[b]			2.7[b]
Jute	(aw)		15.5[b]	50 to 80[b]			2.7[b]
Cashmere	(d)	14.3 to 17	15.5	1¼ to 3½	4000	2.2 to 2.8	2.5
Cotton—Amer. Upland	(aw)	16.8 to 20.2	18	¾ to 1 5/16	1000 to 2400	1.8 to 2.3	2.1
Acetate Rayon—Staple	(aw)	12.5 to 46	18	Any desired length		1.7 to 22	3.3
—Filament	(aw)	12.5 to 21	18	Continuous		1.7 to 4.4	3.3
Nylon	(d)	8 to —	19.5	Any length staple and continuous		0.6 to —	3.3
Camel Hair	(d)	17.3 to 22	20	2 to 2-½	2800	2.8 to 5	4
Cotton—Indian	(aw)	20 to 23	21.5	½ to 1-1/16	500 to 1300	2.3 to 3.8	3.3
Casein Fiber	(d)	11.4 to 28	24			1.6 to 8	5.8
Wool—Apparel	(d)	19 to 40	25	2 to 16	2600 to 10000	3.6 to 16.5	6.4
Ramie	(aw)	24 to 27	25.5[b]	3 to 10[b]			6.7[b]
Alpaca	(d)	24 to 29	27	4 to 8	4000 to 7000	5.3 to 8.6	7.3
Mohair—Kid	(d)	24 to 29	27	5 to 7	5000 to 6000	5.3 to 8.6	7.3
Silk—Tussah	(w)	27 to 30	28.5	Continuous and staple			2.5
Mohair	(d)	34 to 60	40	6 to 12	4500 to 5000	11.5 to 37	16
Human Hair	(d)	40 to 100	60	12 to 36	15000	16.5 to 103	37
Silk—Kuriwata	(w)	50 to 125	90				19
Horsehair—Mane and Tail	(d)	120 to 180	150			150 to 335	240

[a] (d) = mean diameter (of fibers whose cross-section is approximately circular).
(w) = width (of fibers whose cross-section is flat or ribbon shaped).
(aw) = mean width (average of maximum and minimum widths of fibers of ribbon shape or irregular cross-section).

[b] The values for diameters or widths of the vegetable fibers, such as flax, jute, and ramie, are the dimensions of the unit cells. Commercial fibers of these materials are generally composed of groups of unit cells, and the diameters of the commercial fibers depend upon the purification treatment of the raw fibers and therefore vary greatly. Values given for the lengths of these fibers are the lengths of the commercial fibers rather than of the unit cells.

[c] 1 micron = 0.001 mm. = 0.00004 in.

TABLE IV.—FUNDAMENTAL FIBER CHARACTERISTICS.

I. Form	II. Physical	III. Chemical
1. Length	1. Density (specific gravity)	1. Composition
(*a*) Mean length	2. Moisture Absorption	2. Structure
(*b*) Length distribution (staple diagram)	(*a*) Relation between relative humidity and moisture regain	3. Behavior toward
2. Cross-Section	(*b*) Swelling phenomena	(*a*) Acids
(*a*) Mean area	3. Stress-Strain Behavior	(*b*) Alkalies
(*b*) Area distribution	(*a*) Strength	(*c*) Oxidation
(*c*) Shape	(*b*) Elongation	(*d*) Dyes
3. Crimp	(*c*) Stiffness	(*e*) Solvents
(*a*) Frequency (crimps per inch)	(*d*) Toughness	
(*b*) Amplitude	(*e*) Elasticity	
4. Surface Character	(*f*) Resilience	
	4. Inter-Fiber Friction	
	5. Color	
	6. Luster	
	7 Refractive Index	
	8. Scorching or Melting Point	
	9. Specific Heat	
	10. Specific Conductivity	
	(*a*) Heat	
	(*b*) Electricity	

is based on an integrated evaluation of all of these characteristics. In this lecture we shall concentrate principally on the mechanical properties of the materials of which fibers are composed (Group II-3 in Table IV) and on the effect of moisture and heat on these inherent properties, with some consideration also of the influence of the form factors, namely, dimensions and shape, on the mechanical behavior of the fibers themselves.

Although the subject of yarns is beyond the scope of this lecture, I have ventured to list the significant characteristics of spun yarns in Table V to emphasize that yarn character is directly derived from fiber character, modified, of course, by the form factors which define the structure of the yarn.

TABLE V.—SIGNIFICANT CHARACTERISTICS OF SPUN YARNS.

I. Form	II. Physical	III. Chemical
1. Fineness (count) 2 Twist 3. Cross-Section (a) Diameter (b) Compactness 4. Surface Character	1. Stress-Strain Behavior (a) Strength (b) Elongation (c) Stiffness (d) Toughness (e) Elasticity (f) Resilience 2. Evenness 3. Compressibility (Rigidity of cross-section shape)	1. Composition 2. Effect of (a) Acids (b) Alkalies (c) Oxidation (d) Dyes (e) Lubricants (f) Resins (g) Other substances

The densities of the various natural organic fiber materials lie within the range 1.25 to 1.55, but the introduction of manufactured fibers has widened the range of densities at both ends of the scale and has increased the importance of the distinction between *diameter* (or cross-sectional area) and *fineness*. The present-day textile fibers vary in density from nylon, which is the lightest, at 1.14, to glass, which is the heaviest, at 2.54.

The engineer usually thinks of unit strength in terms of force or load per unit area of cross-section, as, for instance, pounds per square inch or kilograms per square millimeter, but the textile technologist thinks of unit strength in terms of load per unit fineness. *Fineness* is here used in an exact sense as a quantity or property of materials having the dimensions: mass per unit length. The physicist's term for fineness is *linear density*. Direct units of fineness which have been used in the textile industry include micrograms per inch, used in cotton fiber work, and denier, the traditional unit of fineness for silk and rayon. *The denier of a fiber or yarn is its linear density or fineness in grams per 9000 meters.* The word, denier, and its present dimension as a unit of fineness had their origin in the practice of the silk merchants of early Europe who used coins called "deniers" as weights in weighing sample skeins of a given length in order to measure the fineness. In the cotton, wool, and most other branches of the industry, fineness is expressed inversely as length per unit weight, and there is a different unit for almost every fiber. For the textile antiquarian, these various units of fineness provide an interesting commentary on the growth of the separate branches of the industry as isolated crafts, but, in the modern textile world in which the walls between the various fiber groups are crumbling, there seems to be little justification for perpetuating the confusion which such a multiplicity of fineness units creates.

Committee D-13 has just taken a courageous step toward eliminating the inconvenience of so many fineness units by broadcasting an explanation of a proposed unit of fineness called *Grex*. *The grex of a fiber, yarn, cord, or rope is its linear density, or fineness, in grams per 10,000 meters.* The merits of the Grex system have been ably presented by A. G. Scroggie during the last six months on behalf of Committee D-13 with the cooperation of the entire textile trade press.[7] Obviously, the introduction of a new unit of measurement into an industry with the generations of tradition and habit on which each of the old branches of the textile industry are based is not easy, but the temporary inconvenience will be so far outweighed by the permanent benefits to every textile firm which is concerned with calculations or commerce in two or more different kinds of fibers or yarns that I believe anyone who tries it will convince himself, as I have convinced myself, that it should be adopted immediately by *all* branches of the textile industry. Appendix A[8] contains the summary of the Grex system as published by A.S.T.M. Committee D-13.

TABLE VI.—AIR-DRY STRENGTH OF SOME FIBER MATERIALS.

Material	Density	Tenacity, g. per gx.	Tensile Stress, psi.
Nylon	1.14	4.0 to 6.3	55 000 to 102 000
Silk (boiled-off)	1.35	2.2 to 4.6	42 000 to 88 000
Wool	1.32	1.1 to 1.5	21 000 to 28 000
Acetate rayon	1.32	1.2 to 1.5	22 000 to 28 000
Vinyl fibers	1.35	1.8 to 3.6	35 000 to 69 000
Hemp	1.49	5.3 to 6.2	112 000 to 132 000
Jute	1.49	2.7 to 5.3	57 000 to 112 000
Flax	1.50	2.4 to 7.0	50 000 to 150 000
Viscose rayon	1.52	1.8 to 4.5	39 000 to 97 000
Saponified acetate rayon	1.52	4.5 to 6.3	97 000 to 136 000
Cotton	1.54	2.0 to 5.0	44 000 to 109 000
Vinylidene fibers	1.72	3.6 to 5.4	88 000 to 132 000
Glass	2.54	6 to 30	217 000 to 1 100 000
Steel (structural)	7.8	0.4 to 1.1	50 000 to 125 000

Fineness is a function of density as well as of cross-sectional area, being proportional to the product of these two. Therefore, the breaking strength per unit fineness (which is called the *tenacity*) is not proportional to the breaking strength per unit cross-section (which is called *tensile strength*) for materials of different densities. Table VI lists the density, the tenacity in grams per grex, and the tensile strength in pounds per square inch for a number of fiber materials, with structural steel included as a reference point.

ON THE EVALUATION OF TEXTILE FABRIC QUALITY

Of the five senses by which we receive impressions of the external world, we use an integration of tactile and visual impressions in the direct evaluation of a textile fabric. Of course, we often supplement this direct sensory impression by secondary impressions gained by subjecting the fabric to a carefully planned series of tests for strength, for warmth, for resistance to deteriorating agents, or for whatever other pertinent specific characteristics cannot be measured by direct sight or touch. In the large and important field of apparel and household textiles, the direct sensory impression plays a major part, and probably always will, regardless of the admirable trend toward certification of tested quality by means of suitable labels. In the field of industrial textiles, the secondary impressions based on quantitative data are usually of greater importance.

However, *apart from that portion of the visual impression which is stimulated solely by color, the visual and the tactile stimuli, that is, the subjective characteristics by which household and apparel fabrics are evaluated, are largely due to the mechanical properties of the fabric and of the fibers of which it is composed. These same mechanical properties are also directly responsible for the objective physical characteristics by which industrial*

---

[7] A. G. Scroggie, "A New Universal Yarn Numbering System," *Rayon Textile Monthly*, Vol. 25, pp. 17 and 69 (1944).

[8] See p. 586.

fabrics are evaluated. Therefore, an engineering approach to the evaluation and utilization of textile fibers seems to me to be of primary importance to an understanding of the ancient invention of textile structure in the light of the new philosophy of textiles which has been created by the introduction of manufactured fibers.

TABLE VII.—TERMS RELATING TO HAND OF FABRICS.
(Supplement III, p. 370, 1943 Edition, A.S.T.M. Standards on Textile Materials)

Physical Property	Explanatory Phrase	Terms to be Used in Describing Range of Corresponding Component of Hand
Flexibility	Ease of bending	Pliable (high) to stiff (low)
Compressibility	Ease of squeezing	Soft (high) to hard (low)
Extensibility	Ease of stretching	Stretchy (high) to nonstretchy (low)
Resilience	Ability to recover from deformation	Springy (high) to limp (low). Resilience may be flexural, compressional, extensional, or torsional
Density	Weight per unit volume (based on measurement of thickness[a] and fabric weight)	Compact (high) to open (low)
Surface Contour	Divergence of the surface from planeness	Rough (high) to smooth (low)
Surface Friction	Resistance to slipping offered by the surface	Harsh (high) to slippery (low)
Thermal Character	Apparent difference in temperature of the fabric and the skin of the observer touching it	Cool (high) to warm (low)

[a] Thickness measurements and weight are made in accordance with the procedures described in the A.S.T.M. methods for specific fabrics.

This viewpoint is supported by an inspection of Table VII, "Terms Relating to Hand of Fabrics," which was compiled and published by Committee D-13.[9] In this table, eight physical properties are listed as related to the "hand" of a fabric (which is the common trade name for the feel, or tactile sensation). All of these terms, with the possible exception of the last, are certainly familiar to the engineer and it is obvious that the first four, namely, flexibility, compressibility, extensibility, and resilience are important to an understanding of all engineering materials. Although the table is concerned only with hand, one or more of these same physical properties are also directly responsible for the draping qualities of fabrics and, to a considerable extent, for the appearance or surface texture.

These mechanical properties of the fabric are dependent, in part, upon the mechanical properties of the fibers of which the fabric is composed; in part, upon the structural arrangement of the fibers in the yarns and of the yarns in the fabric; and, in part, upon the nature of the fabric finishing operations. In this lecture, we shall confine ourselves to an engineering study of fibers and leave the equally important engineering approach to yarn and fabric structure for future consideration.

THE MECHANICS OF TEXTILE FIBERS

The behavior of a body (whether it be a beam of wood or of steel or of reinforced concrete, a wire strand in a suspension cable, or a single textile fiber) under the influence of external forces which tend to stretch or compress or bend or twist it, depends upon three major factors:

- (*a*) The nature of the material of which the body is made.
- (*b*) The dimensions of the body.
- (*c*) The shape of the body.

---

[9] *Standards on Textile Materials,* Am. Soc. Testing Mats., p. 370 (1943). (Issued as separate publication.)

The Influence of Fiber Material on Fiber Behavior

Treatises on the strength of materials as, for instance, section 5 of L. S. Mark's "Mechanical Engineers' Handbook,"[10] which is concerned chiefly with massive structural materials such as metals, wood, and concrete, remind us that *the nature of a material* with respect to its behavior under the influence of external forces, that is, its mechanical properties, is described by a few qualities of which the five basic ones, namely, strength, stiffness, elasticity, resilience, and toughness, are presented in Table VIII.

TABLE VIII.—BASIC MECHANICAL PROPERTIES OF MATERIALS.

Quality	Service Rendered	Criterion
A. Strength........	To carry a dead load.	Ultimate strength
B. Stiffness........	To carry a load without deformation.	Modulus of elasticity
C. Elasticity.......	To undergo deformation and return to original shape upon cessation of deforming force.	Elastic limit
D. Resilience......	To absorb shock without permanent deformation.	Modulus of resilience
E. Toughness......	To endure large, permanent deformations without rupture.	Ultimate resilience

Complete knowledge of the behavior of a substance with respect to these five primary qualities involves a knowledge of its behavior under three kinds of forces, namely, tensile, compressive, and shearing forces, and a knowledge of the influence on this mechanical behavior, of time, of temperature, and, in the case of hydrophilic substances such as wood and most textile fibers, of moisture. Bending produces simultaneous tensile and compressive stresses within the material and is, therefore, a derivative of the tensile and compressive behavior. Torsion, or twisting, produces shearing stresses within the substance and is, therefore, a derivative of shearing behavior.

Quantitative information about a material with respect to these five primary mechanical properties is obtained by subjecting a specimen of the substance to stresses (tensile, compressive, or shearing) and observing the deformation at various amounts of stress. The most common procedure is to increase the stress at a gradual rate from zero to rupture. The influence of time is observed by varying the rate of increase of the stress between two limiting extremes. One limit is an infinitely slow rate of loading (creep test), carried out in practice by observing the behavior of the substance under different constant loads. The other limit is an infinitely fast rate of loading. Impact tests are the nearest practical approach to this upper limit of rate of loading and are carried out by observing the behavior of the substance under the shock of a sudden stress such as that produced by a falling weight.

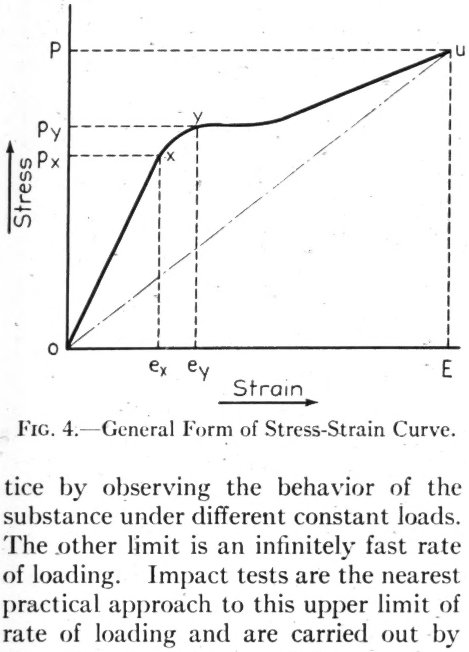


FIG. 4.—General Form of Stress-Strain Curve.

Most mechanical testing is done at a uniform rate of loading, the rate being slow enough to permit the observation or the automatic recording of simultaneous readings of load and elongation from which data the stress-strain curve is plotted.

The general form of such a stress-strain curve is given in Fig. 4. Such a curve shows not only the deformation (in terms of unit strain) produced in a material by every load (in terms of unit stress) from zero to the breaking load (ultimate stress), but also provides a graphic explanation of the criteria by which the other basic qualities of elasticity, stiffness, resilience, and toughness are quantitatively described.

---

[10] L. S. Mark, *Mechanical Engineers' Handbook*, Fourth Edition, McGraw-Hill Book Co., Inc., New York, N. Y. (1941).

Stiffness is measured by the slope of the elastic portion *o-x* of the stress-strain curve and equals p_x/e_x. As a practical approximation, the slope of a straight line drawn from *o* to the yield point *y* (which lies close to *x* in the case of most nontextile structural materials) is generally used as a measure of stiffness which is therefore computed from p_y/e_y. In engineering and scientific literature, the true significance of this particular measure of stiffness is invariably masked for many of us under the formidable names, "modulus of elasticity" or "Young's modulus." I strongly urge the use of the simple, descriptive name, "elastic stiffness," whenever this criterion is used in textile literature, whether of highly scientific or of technological nature.

Elasticity is measured by the stress p_y at the yield point *y* (elastic limit). The yield strain e_y is also of importance in materials of high extensibility.

Resilience is measured by the area o-y-e_y-o under the elastic portion of the stress-strain curve. This area expresses, in terms of the stress and strain dimensions of the chart, the work required to deform the material to its elastic limit *y* and, therefore, the recoverable work stored up in the material at its elastic limit.

Toughness is measured by the area *o-y-u-E-o* under the stress-strain curve. This area expresses, in terms of the stress and strain dimensions of the chart, the total work required to rupture the material.

In addition to these five basic qualities of behavior of a material under the influence of external forces, there are other mechanical qualities of importance to the engineer. For specific purposes, some of these other qualities may be more important than the five which we have already described, but they are, nevertheless, secondary rather than basic because they are, in general, dependent on the magnitude of one or more of the basic qualities. Among these secondary qualities may be mentioned ***hardness***, ***ductility***, and ***fatigue***.

A Systematic Analysis of the Mechanical Behavior of Fiber Materials:

With this brief résumé of the engineering analysis of the behavior of materials under stress as a foundation for those who are either unfamiliar with that phase of engineering education known as "strength of materials" or whose classroom training in the subject is as far away along the time axis as is mine, I would like to propose a system of evaluating the mechanical properties of textile fibers which should be at least of passing interest to the materials engineer who is accustomed to working with massive structural materials, and of lasting interest and practical value to every textile technician who deals with the conversion of fibers into yarns and yarns into fabrics, whether for industrial, for household, or for apparel purposes. This system is outlined in Table IX, in which six basic qualities are defined. Quantitative criteria for each quality are named and defined. The formula for the computation of each criterion is given, as are also the dimensions in metric engineering units and in textile units. (In order to avoid encumbering with minutiae the general exposition of this scheme, I have placed in Appendix C[11] the deriva-

---

[11] See p. 588.

TABLE IX.—PROPOSED SYSTEM FOR EVALUATING BASIC MECHANICAL PROPERTIES OF TEXTILE FIBER MATERIALS UNDER THE INFLUENCE OF TENSILE FORCES.

Quality	Definition of Quality	Quantity	Symbol	Definition of Quantity	Formula	Dimensions			
						Engineering Units (metric)		Textile Units[a] (grex)	
						Complete Dimension	Net Dimension	Complete Dimension	Net Dimension
Strength	The ability to support a load	BREAKING STRESS	P	The stress required to produce rupture	$P = \frac{F_u}{A}$ or $P = \frac{F_u}{f}$	$\frac{\text{kg.}}{\text{mm.}^2}$	$\frac{\text{kg.}}{\text{mm.}^2}$	$\frac{\text{g.}}{\text{gx.}}$	$\frac{\text{g.}}{\text{gx.}}$
		Stress at any strain e	p_e	The stress required to produce strain e	$p_e = \frac{F_e}{A}$ or $p_e = \frac{F_e}{f}$				
Elongation	The deformation produced by a load, along the line of action of the load	BREAKING STRAIN	E	The strain at the breaking stress	$E = \frac{l_u}{L}$	$\frac{\text{cm.}}{\text{cm.}}$	Dimensionless ratio	$\frac{\text{cm.}}{\text{cm.}}$	Dimensionless ratio
		Strain at any stress p	e_p	The strain at stress p	$e_p = \frac{l_p}{L}$				
Stiffness	Resistance to deformation	AVERAGE STIFFNESS	S_a	The ratio of breaking stress to breaking strain	$S_a = \frac{P}{E}$	$\frac{\frac{\text{kg.}}{\text{mm.}^2}}{\text{strain}}$	$\frac{\text{kg.}}{\text{mm.}^2}$	$\frac{\frac{\text{g.}}{\text{gx.}}}{\text{strain}}$	$\frac{\text{g.}}{\text{gx.}}$
		Elastic stiffness	S_y	The ratio of stress to strain at the yield point	$S_y = \frac{p_y}{e_y}$				
		Stiffness to any stress p	S_p	The ratio of stress to strain at stress p	$S_p = \frac{p}{e_p}$				
		Stiffness to any strain e	S_e	The ratio of stress to strain at strain e	$S_e = \frac{p_e}{e}$				
Toughness	The ability to absorb work	TOUGHNESS INDEX	W_i	The work, per unit volume (or per unit fineness) of material, which would cause rupture if the stress-strain curve were a straight line	$W_i = \frac{PE}{2}$	$\frac{\text{kg.mm.}}{\text{mm.}^3}$	$\frac{\text{kg.}}{\text{mm.}^2}$	$\frac{\text{g.cm.}}{\text{gx.cm.}}$	$\frac{\text{g.}}{\text{gx.}}$
		Unit breaking toughness	W_u	The work of rupture per unit volume (or per unit fineness) of material	$W_u = \int_o^E p\, de$				
		Unit toughness to stress p	W_p	The work, per unit volume (or per unit fineness) of material, required to produce stress p	$W_p = \int_o^{e_p} p\, de$				
		Unit toughness to strain e	W_e	The work, per unit volume (or per unit fineness) of material, required to produce strain e	$W_e = \int_o^e p\, de$				

Elasticity	The ability to return to original shape and dimensions upon cessation of deforming force	Yield stress	p_y	The stress at the yield point (elastic limit)	$p_y = \frac{F_y}{A}$ or $p_y = \frac{F_y}{f}$	$\frac{kg.}{mm.^2}$	$\frac{kg.}{mm.^2}$	$\frac{g.}{gx.}$	$\frac{g.}{gx.}$
		Yield strain	e_y	The strain at the yield point (elastic limit)	$e_y = \frac{l_y}{L}$				
		Degree of elasticity at any stress p	$D.E._p$	The ratio of recoverable strain to strain at stress p	$D.E._p = \frac{e_p - e_r}{e_p}$	$\frac{cm.}{cm.}$	Dimensionless ratio	$\frac{cm.}{cm.}$	Dimensionless ratio
		Degree of elasticity at any strain e	$D.E._e$	The ratio of recoverable strain to strain e	$D.E._e = \frac{e - e_r}{e}$				
Resilience	The ability to absorb work without suffering permanent deformation.	Unit yield resilience	R_y	The (recoverable) work, per unit volume (or per unit fineness) of material, at the yield point	$Ry = \frac{p_y e_y}{2}$				
		Unit resilience at any stress p	R_p	The recoverable work, per unit volume (or per unit fineness) of material, at stress p	$R_p = \int_{e_r}^{e_p} p'\,de$	$\frac{kg.mm.}{mm.^3}$	$\frac{kg.}{mm.^2}$	$\frac{g.cm.}{gx.cm.}$	$\frac{g.}{gx.}$
		Unit resilience at any strain e	R_e	The recoverable work, per unit volume (or per unit fineness) of material, at strain e	$R_e = \int_{e_r}^{e} p'\,de$				
		Degree of resilience at any stress p	$D.R._p$	The ratio of recoverable work to total work at stress p	$D.R._p = \frac{\int_{e_r}^{e_p} p'\,de}{\int_{o}^{e_p} p\,de}$	$\frac{\frac{kg.mm.}{mm.^3}}{\frac{kg.mm.}{mm.^3}}$	Dimensionless ratio	$\frac{\frac{g.cm.}{gx.cm.}}{\frac{g.cm.}{gx.cm.}}$	Dimensionless ratio
		Degree of resilience at any strain e	$D.R._e$	The ratio of recoverable work to total work at strain e	$D.R._e = \frac{\int_{e_r}^{e} p'\,de}{\int_{o}^{e} p\,de}$				

---

[a] In textile technology, dimensions of mechanical properties are usually expressed in terms of unit fineness (linear density) instead of in terms of unit cross sectional area. Th word *tenacity* replaces the word *stress* when the stress is expressed as load per unit fineness, for example, grams per grex.

tion of the formulas and dimensions listed in Table IX, and have included there a more detailed discussion of the qualities and quantities for those who may put the proposed system to use.)

There is nothing new or radical about the concepts of mechanical behavior in this scheme which embraces the basic criteria that have long been used by engineers in the selection and use of other materials of construction, and by scientists in fundamental researches on the relations between the internal structure and the mechanical behavior of high polymers, including fibers. Its novelty lies rather in the attempt to systematize and clarify the engineering concepts by the use of terms, definitions, and symbols for the basic quantitative criteria which are directly descriptive of the subjective qualities by which fibers, yarns, and fabrics are evaluated by that ultimate testing machine, the human sensory system of the textile technician and the textile consumer.

Nevertheless, while designed to make the terminology understandable and useful to the nonengineering mind, the treatment adheres to the true engineering method of basing the concepts on the firm foundation of physical theory and experimental fact, tempered by the necessities of practical application. The concepts are equally applicable to the evaluation of tensile, compressive, or shearing behavior, or to the derivative bending and torsional behavior. For simplicity in presentation and because of the greater availability of data, Table IX is confined to tensile behavior.

Because of the anisotropic nature of the internal structure of fibers, their physical properties are undoubtedly not of equal magnitude lengthwise and crosswise, as is the case in some massive structural materials. The experimental difficulties imposed by the fiber shape and dimensions make difficult the determination of behavior at right angles to the fiber axis, and little or no data of this type are available. The bending behavior and the torsional behavior of textile fibers are at least as important as the tensile behavior. Some good data exist, but there is great need for standardized test methods and for more data on these two derived properties.

The most widely used physical test of manufactured fibers is the determination of breaking strength and breaking elongation of single fibers or of small groups of parallel fibers in the form of continuous filament yarn. In the case of continuous filament yarns, their high degree of uniformity of size makes reliable the calculation of breaking stress or breaking tenacity from the measured breaking load and yarn number (fineness). In the case of single fibers, the degree of variation of cross-sectional area from fiber to fiber and, in the case of the natural fibers, even within short lengths of the same fiber, makes the calculation of stress from the observed load less dependable, but some data on breaking stress or on breaking tenacity of natural fibers and considerable data on manufactured fibers are available.

Existing A.S.T.M. textile specifications prescribe standard methods of testing the breaking strength of fiber bundles of cotton fibers and of rayon staple fibers; and the breaking strength of single strands of rayon filament yarn, spun rayon yarn, rayon tire cord, cotton tire cord, and cotton, asbestos, linen, ramie, hemp, glass, jute, woolen, worsted, and mixed fiber yarns. Except for tire cord, however, no mention is made of measuring and reporting elongation. I recommend strongly that the determination of elongation be incorporated into every one of the Society's standards for the testing of textile fibers and textile yarns.

If the *breaking stress* P in terms of either tensile strength or tenacity, and

TABLE X.—GENERAL INDICES OF MECHANICAL CHARACTER OF FIBER MATERIALS (P, S_a, W_i VALUES).
(Extracted from Table IX)

Quality	Definition of Quality	Quantity	Symbol	Definition of Quantity	Formula	Dimensions			
						Engineering Units (metric)		Textile Units[a] (grex)	
						Complete Dimension	Net Dimension	Complete Dimension	Net Dimension
Strength	The ability to support a load	BREAKING STRESS	P	The stress required to produce rupture	$P = \frac{F_u}{A}$ or $P = \frac{F_u}{f}$	$\frac{\text{kg.}}{\text{mm.}^2}$	$\frac{\text{kg.}}{\text{mm.}^2}$	$\frac{\text{g.}}{\text{gx.}}$	$\frac{\text{g.}}{\text{gx.}}$
Elongation	The deformation produced by a load, along the line of action of the load	BREAKING STRAIN	E	The strain at the breaking stress	$E = \frac{l_u}{L}$	$\frac{\text{cm.}}{\text{cm.}}$	Dimensionless ratio	$\frac{\text{cm.}}{\text{cm.}}$	Dimensionless ratio
Stiffness	Resistance to deformation	AVERAGE STIFFNESS	S_a	The ratio of breaking stress to breaking strain	$S_a = \frac{P}{E}$	$\frac{\frac{\text{kg.}}{\text{mm.}^2}}{\text{strain}}$	$\frac{\text{kg.}}{\text{mm.}^2}$	$\frac{\frac{\text{g.}}{\text{gx.}}}{\text{strain}}$	$\frac{\text{g.}}{\text{gx.}}$
Toughness	The ability to absorb work	TOUGHNESS INDEX	W_i	The work, per unit volume (or per unit fineness) of material, which would cause rupture if the stress-strain curve were a straight line	$W_i = \frac{PE}{2}$	$\frac{\text{kg.mm.}}{\text{mm.}^3}$	$\frac{\text{kg.}}{\text{mm.}^2}$	$\frac{\text{g.cm.}}{\text{gx.cm.}}$	$\frac{\text{g.}}{\text{gx.}}$

---

[a] In textile technology, dimensions of mechanical properties are usually expressed in terms of unit fineness (linear density) instead of in terms of unit cross-sectional area. The word *tenacity* replaces the word *stress* when the stress is expressed as load per unit fineness, for example, grams per grex.

the *breaking strain* E in terms of unit elongation (one hundredth of the percentage elongation) are known, the *average stiffness* $S_a = \frac{P}{E}$ and the *toughness index* $W_i = \frac{PE}{2}$ can be computed. These two indices are based on the arbitrary assumption that the stress-strain curve is a straight line connecting the origin o with the breaking point u (Fig. 4). Since the actual stress-strain curve for each commercial textile fiber lies above this straight line, these stiffness and toughness indices will be conservative. Table X shows the part of the scheme which can be based on tests of tenacity and elongation when the stress-strain curve is not available.

TABLE XI.—GENERAL INDICES OF MECHANICAL CHARACTER OF SOME FIBER MATERIALS (P-S_a-W_i VALUES).

Tenacity		Average Stiffness		Toughness Index	
Fiber Material	P $\frac{g.}{gx.}$	Fiber Material	S_a $\frac{g.}{gx.}$	Fiber Material	W_i $\frac{g.\ cm.}{gx.\ cm.}$
Saponified Acetate	6.3	Glass	290	Vinylidene	0.56
Glass	5.8	*FLAX*	270	Nylon (reg.)	0.45
Nylon (strong)	5.8	*HEMP*	200	Nylon (strong)	0.41
FLAX	5.5	*JUTE*	185	*SILK* (Boiled off)	0.40
RAMIE	5.0	*ABACA* (Manila "Hemp")	175	Acetate H. I.	0.32
ABACA (Manila "Hemp")	4.6	*RAMIE*	167	*SILK* (Tussah)	0.30
Viscose—G	4.5	*SISAL*	127	Vinyl—E	0.30
Nylon (reg.)	4.5	Saponified Acetate	105	Vinyl—1.	0.30
Vinylidine	4.5	Viscose—G	75	Vinyl—2.	0.25
HEMP	4.0	*COTTON*	57	Viscose H. T.	0.20
COTTON	4.0	Nylon (strong)	41	*WOOL*	0.20
SILK (Tussah)	3.8	*SILK* (Tussah)	24	Viscose M.T.	0.19
SISAL	3.7	Viscose H.T.	23	Saponified Acetate	0.19
SILK (boiled off)	3.5	Nylon (reg.)	22	Viscose R.T.	0.17
Vinyl—2	3.3	Vinyl—2	22	Acetate R.T.	0.16
Viscose H.T.	3.0	Vinylidene	18	*COTTON*	0.14
JUTE	2.8	*SILK* (Boiled off)	15	Casein	0.14
Viscose M.T.	2.4	Viscose M.T.	15	Viscose—G	0.14
Vinyl—1	2.0	Cuprammonium R.T.	14	Cuprammonium R.T.	0.13
Cuprammonium R.T.	1.9	Viscose R.T.	10	*RAMIE*	0.08
Viscose R.T.	1.8	Vinyl—1	7	*ABACA* (Manila "Hemp")	0.07
Acetate R.T.	1.3	Acetate R.T.	5	Glass	0.06
WOOL	1.3	*WOOL*	4	*FLAX*	0.06
Acetate H.I.	1.3	Acetate H.I.	3	*SISAL*	0.05
Casein	0.7	Casein	2	*HEMP*	0.04
Vinyl—E	0.15	Vinyl—E	0.04	*JUTE*	0.02

The three values P, S_a, and W_i which can be thus obtained from the measurement of the tenacity and breaking elongation of a fiber give a much better indication of the textile "personality" of the fiber material than can be obtained from P alone or even from P and E. It is obvious that values for *elastic stiffness* S_y, *yield stress* p_y, and *resilience* R_y are needed to fill in the elastic details of the fiber "portrait" and that the actual stress-strain curve will yield more accurate information than the straight-line approximation. Nevertheless, much can be learned from the P-S_a-W_i indices. Table XI gives the average values of these criteria for 26 different fibers as determined from a compilation of data from over 30 different sources. In Fig. 5, these values are charted as relative tenacity, relative average stiffness, and relative toughness index, respectively, on scales in which the stiffest, the strongest, and the toughest fiber material listed in Table XI are each rated 100.

In examining this table and chart, I must ask you to temper with charity the indignation which you will probably feel, if your favorite fiber material is not blessed with the perfect combination of stiffness, strength, and toughness. This charity is solicited because dependable comparable data on breaking stress and breaking elongation of many fiber materials, particularly those of natural origin, are not plentiful. There is no doubt in my own mind that the accumulation of additional dependable data on each fiber material will result in shifting some of them up or down each of the three scales. I have two proposals for facilitating such adjustments. One is to ask each interested person to send me references to any published data, or any unpublished data of his own, which should be put into the pot in which these figures were brewed in order to improve the authenticity of this table and chart. My second proposal (based on a suggestion received by the Textile Research Institute) is that some research organization such as that institute, the Textile Foundation, or the Textile Section of the National Bureau of Standards make a series of tests of all of the natural and manufactured fibers under uniform conditions of temperature, relative humidity, and rate of loading in order to provide the textile industry with comparable data on these basic qualities of fiber materials.

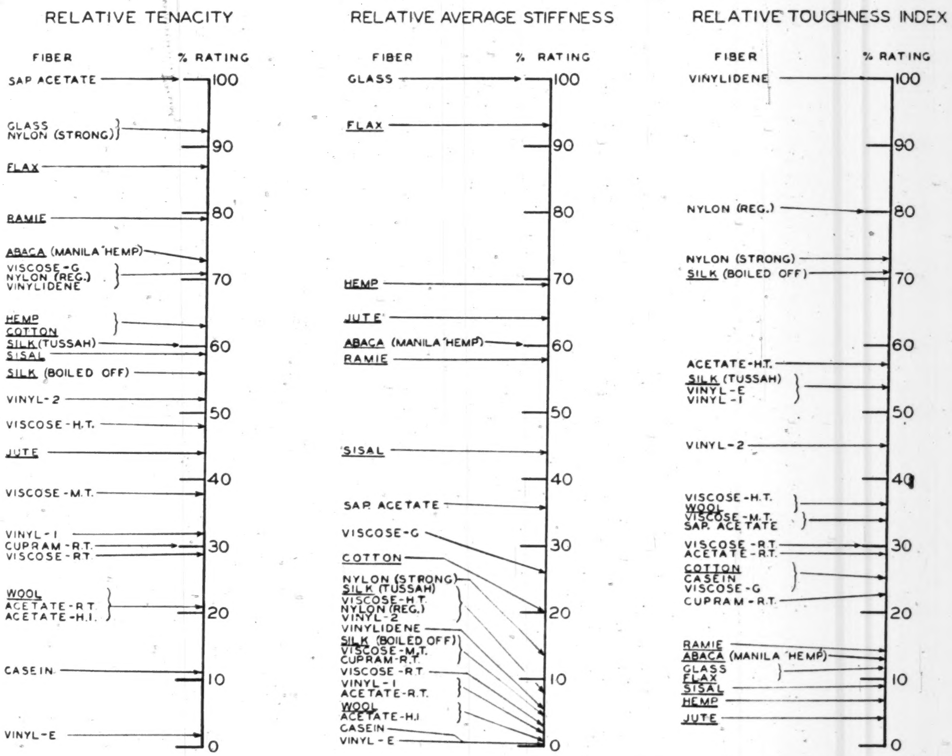


FIG. 5.—Relative Scale of General Indices of Mechanical Character of Some Fiber Materials.

Meanwhile, this preliminary compilation can be studied with profit, for it clarifies some things that a textile man knows by empirical experience, and reveals some things that many of us may not have known or understood. Remember that we are now discussing the *unit values or indices of the properties of* FIBER MATERIALS and that, as we shall see shortly, the stiffness, strength, and toughness of the fibers themselves are influenced by their shape and dimensions as well as by the properties of the materials of which they are composed. This distinction is analagous to that in the field of metals, where the unit values of strength, etc., for a given type of steel are the basic data by which the engineer can understand his raw material. These inherent substance properties are responsible in part for the mechanical behavior of a beam of that steel, but its actual strength, stiffness, etc., are dependent also on its shape and dimensions. Because textile fibers are such tiny beams, this distinction is harder to remember, but it is equally important.

Just as the adjectives "hot" and "cold" describe the opposite ends of a temperature scale or provide a non-numerical way of describing the relative degree of hotness of one or more objects, so we can describe the range of each of these three mechanical qualities on the numerical scales of Table XI or on the percentage scales of Fig. 5 thus:

Strength or tenacity ranges from *strong* to *weak*.
Stiffness ranges from *stiff* to *pliant*.
Toughness ranges from *tough* to *yielding*.

Table XI indicates, for example, that silk substance is several times stiffer than wool substance, and that cotton substance is several times stiffer than silk substance; while glass substance, at the top of the stiffness scale, is some seventy-five times stiffer than wool substance. Acetate rayon is about as pliant as wool, and viscose rayon is comparable to silk in its pliancy (or stiffness).

Some of the strongest fiber substances (such as glass, flax, ramie) are very stiff, but very low on the toughness scale, that is, very yielding. This combination spells brittleness. The combination of low toughness and low strength, on the other hand, means excessive softness and makes a poor fiber.

Some fibers, such as wool, regular acetate rayon, and high impact acetate rayon are approximately equal in strength, but differ in toughness.

From these data, the personalities of some fiber materials might be characterized as follows:

Wool—very pliant, weak, but tough.
Silk—pliant, moderately strong, and very tough.
Cotton—moderately stiff, moderately strong, and moderately tough.
Flax—very stiff, very strong, but very yielding (brittle).

These three quality indices provide a general guide to the mechanical nature of a fiber substance which is far more enlightening than breaking strength alone, on which we have all been inclined to lean too heavily in the past. They are an answer to the question, "Can a fiber material take it?" They do not, however, tell us anything about the elasticity or resilience of the fiber. These criteria do not answer the question, "Can a fiber material take it and hand it right back?" For this we must have some sort of stress-strain curve and, when we turn to the traditional type of curve which has served our purpose thus far, we find it inadequate because most textile fiber materials exhibit the complex plastic-elastic behavior which is characteristic of high polymeric materials in general rather than the simpler behavior of crystalline structures such as the metals.

The typical stress-strain curve for many metals at room temperatures has a rather sharply defined yield point below which the metal is essentially elastic and above which it is essentially plastic. Therefore, the location of the yield point in the curve permits the ready determination of elastic limit, elastic stiffness, and resilience. The elastic limit is read directly from the yield point. The elastic stiffness is computed from the slope of the curve between the origin and the yield point. The resilience is computed from the area under that portion of the curve between the origin and the yield point.

In the case of fiber materials, however, the very structure which makes them useful for textiles results in a much more complex behavior under stress. Elastic and plastic phenomena are concurrent, rather than consecutive. Furthermore, the elastic reaction itself is not wholly instantaneous, as in the case of a metal, but exhibits "laziness"; that is, if a given load which is within the elastic limit is applied to a fiber material, the material does not stretch instantly to the corresponding elongation, but stretches part way rapidly and then creeps, slower and slower, until it finally reaches its equilibrium elongation. When the load is removed, the fiber material contracts rapidly at first, and then creeps, slower and slower, until it reaches its original length.

Consequently, the actual course of the stress-strain curves of fiber materials are much more dependent upon time (rate of loading) than are the stress-strain curves of metals, and the location, the sharpness, and even the presence of a yield point are largely dependent upon the experimental conditions of the tension test. This is illustrated by Fig. 6, which reproduces actual stress-strain curves of a few fiber materials made in the usual way at a constant rate of loading of 4 g. per denier per min.

There are many publications which deal with the elastic-plastic behavior of fiber materials. For those who wish to pursue the subject in detail, one of the best analyses of the relation between internal structure and this complex behavior is a paper by Press and Mark.[12] Leaderman[13] has reviewed the historical development of the subject of elasticity and creep in filamentous materials in the book which records his own painstaking investigations in this field.

With the engineer's enthusiasm to reduce theory and experiment to some sort of practical working philosophy, let us return to Table IX and to the problem of providing usable criteria of mechanical behavior of fiber materials for textiles.

The *unit breaking toughness* can be determined from the usual stress-strain curve (Fig. 4) by computing, in terms of the units used to plot stress and strain, the area under the entire actual stress-strain curve. The unit breaking toughness will always be larger than the toughness index because the actual stress-strain curve always lies above the straight line connecting the origin with the breaking point. Breaking toughness is an accurate measure of the work required to rupture the fiber material (under the test conditions).

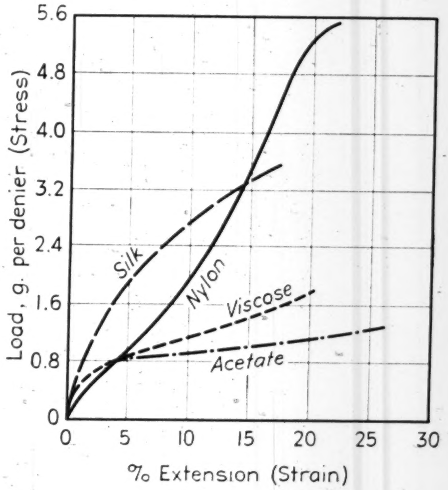


FIG. 6.—Stress-Strain Curves of Some Fiber Materials.

From G. Loasby, *Journal*, Textile Inst., Vol. 34, p. 51 (1943).

The *unit toughness* up to any given stress (or any given strain) can be similarly computed from the area under the stress-strain curve between the origin and the given stress (or strain).

---

[12] J. Press and H. Mark, "Elasticity, Creep, and Recovery of Acetate and Viscose Rayon Yarns," *Rayon Textile Monthly*, Vol. 24, pp. 297, 339, and 405 (1943).

[13] H. Leaderman, "Elastic and Creep Properties of Filamentous Materials and Other High Polymers," The Textile Foundation, Washington, D. C. (1943).

If the stress or strain selected is the yield point, that is, the elastic limit of the material, then the unit toughness becomes the *unit yield resilience*, a measure of the maximum recoverable work which the material can absorb without permanent deformation, or, in other words, a measure of its springiness or liveliness. Furthermore, the stiffness computed from the stress and strain at the yield point is the *elastic stiffness*, a true measure of the inherent stiffness of the fiber material below its elastic limit, which means under most conditions of household and apparel use and many conditions of industrial use. The elastic stiffness is usually greater than the average stiffness.

This brings us right back to the fact that we cannot determine the elastic limit of a fiber material from a yield point on the simple stress-strain curve which we have used thus far. Before we discard this curve and turn to the problem of how to get usable data on elastic limit and resilience, I would like to use the idealized elastic portion of the traditional curve to visualize the wide range of textile character obtainable in fiber materials by selecting or creating materials with different combinations of yield stress and yield strain, that is, elastic strength and elongation.

In Fig. 7, the interrelation of yield

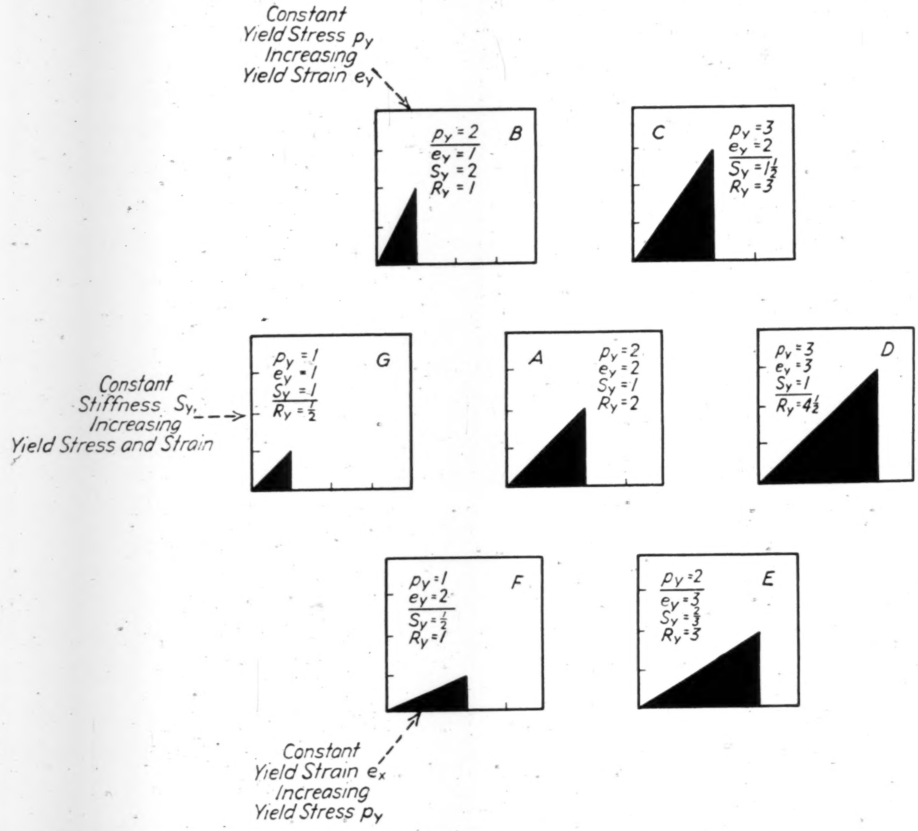

Constant
Yield Stress p_Y
Increasing
Yield Strain e_Y
$p_Y = 2$
$e_Y = 1$
$S_Y = 2$
$R_Y = 1$
B
C
$p_Y = 3$
$e_Y = 2$
$S_Y = 1\frac{1}{2}$
$R_Y = 3$
Constant
Stiffness S_Y
Increasing
Yield Stress and Strain
$p_Y = 1$
$e_Y = 1$
$S_Y = 1$
$R_Y = \frac{1}{2}$
G
A
$p_Y = 2$
$e_Y = 2$
$S_Y = 1$
$R_Y = 2$
$p_Y = 3$
$e_Y = 3$
$S_Y = 1$
$R_Y = 4\frac{1}{2}$
D
$p_Y = 1$
$e_Y = 2$
$S_Y = \frac{1}{2}$
$R_Y = 1$
F
$p_Y = 2$
$e_Y = 3$
$S_Y = \frac{2}{3}$
$R_Y = 3$
E
Constant
Yield Strain e_x
Increasing
Yield Stress p_Y

FIG. 7.—Relationship Between Stress, Strain, Stiffness, and Resilience at the Yield Point.

stress and strain, elastic stiffness, and resilience is portrayed. Only the elastic portion of the stress-strain curve is drawn (as a straight line) and the area under part of the curve is blacked in. The elastic stiffness, computed from the slope of the curve; and the resilience, computed from the area under the curve, are tabulated for three sets of conditions, as follows:

(*a*) Doubling and trebling the yield strain e_y at constant yield stress p_y.

(*b*) Doubling and trebling the yield stress p_y at constant yield strain e_y.

(*c*) Doubling and trebling the yield point (yield stress and strain) at constant elastic stiffness S_y.

The relationships revealed by this graphic analysis may be summarized as follows:

At constant yield stress p_y, the elastic stiffness is inversely proportional to the yield strain, and the resilience is directly proportional to the yield strain and inversely proportional to the elastic stiffness.

At constant yield strain e_y, the elastic stiffness is directly proportional to the yield stress, and the resilience is directly proportional to the yield stress and also to the elastic stiffness.

At constant elastic stiffness S_y, the yield stress is directly proportional to the yield strain, and the resilience is directly proportional to the square of the yield stress and to the square of the yield strain.

Inasmuch as good resilience is more to be desired in fiber materials for textiles than mere strength, the attention of fiber creators might well be directed to the following facts derived from this analysis:

1. An increase in either the yield stress or the yield strain will increase the resilience in direct proportion. However,

(*a*) increasing the yield stress will *increase* the elastic stiffness, whereas

(*b*) increasing the yield strain will *decrease* the elastic stiffness.

2. If the elastic stiffness is to be held constant, the only way to increase the resilience is to increase the yield stress and strain in equal proportions. This will move the yield point outward, that is, lengthen the straight-line portion of the stress-strain curve. The resilience will increase as the square of the yield stress (or yield strain).

3. There must be an optimum elastic stiffness from the standpoints of fabric hand and of brittleness under flexure. Increases in resilience obtained by exceeding this optimum stiffness are purchased too dearly, except for special purposes for which stiffness is more important than other characteristics.

Considerations such as these emphasize the desirability of an experimental technique which will provide data on the elastic behavior of fiber materials. However, no standard method or methods for determining the elasticity and the resilience of fiber materials exist in this country. I recommend this to A.S.T.M. Committee D-13 as an important field for further usefulness to the textile industry. We need, first, the promulgation of a standard method of obtaining the usual stress-strain curve as a basis for determining stress, strain, stiffness, and toughness criteria such as those which we have been discussing. Secondly, we need the development and promulgation of a method of obtaining stress-strain behavior which will enable us to determine the elastic limit in terms of yield stress and strain, the elastic recovery from any given stress or strain, the yield resilience, and the resilient recovery from any given stress or strain. An interesting beginning of the study of resilience measurements was made by a special subcommittee of Committee D-13 under the chairmanship of F. D. Pilgrim, but was interrupted at an early stage by the war.[14]

In addition to the standardization of methods of determining stiffness, toughness, elasticity, and resilience of fiber materials in the form of fibers or filament yarns at ordinary rates of loading, standard tests at two other rates of loading should be developed: one at a very slow rate approaching creep at constant load, and one at a fast rate approaching instantaneous impact or shock. These three tests would provide a sound engineering basis for predicting the performance of fiber materials in textiles according to their intended use.

A number of investigators have approached the problem of measuring the elastic properties of fiber materials on existing constant-rate-of-loading testing machines by performing a series of loading and unloading cycles which results in the type of curve shown in Fig. 8. Such a curve is made on the inclined plane tester which is normally adjusted to load and unload the fiber material at a constant rate of 4 g. per denier per min. The specimen is stressed until a predetermined strain is reached (5 per cent in the case of the silk and nylon curves in Fig. 8), then unloaded to zero stress, then reloaded until the next predetermined stress is reached (10 per cent in the case of these curves), then unloaded to zero stress, and so on until the specimen breaks. By repeating the experiment on fresh specimens at various strain intervals, the elastic limit, or yield point, for the conditions of the test can be determined as the maximum stress (and strain) from which the material will contract to its original length upon returning to zero load. By comparing Fig. 8 with Fig. 6, it will be observed that, for each fiber material Fig. 8, the composite curve described by the first loading cycle and the upper part of the succeeding loading cycles is essentially the same as that of the simple stress-strain curve of the same fiber material in Fig. 6.

The committee on textile standards (Normenauschuss) in Germany has pre-

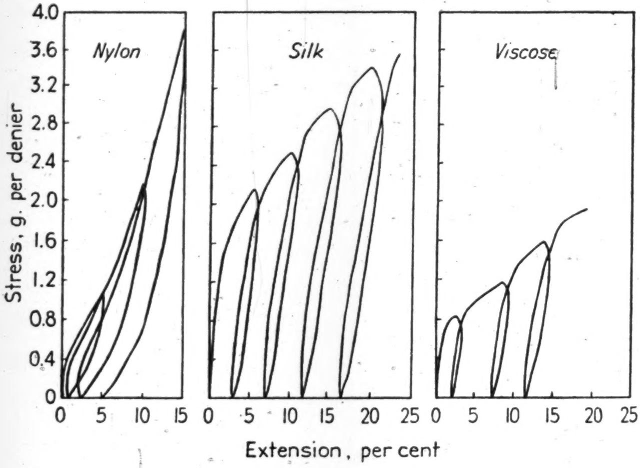


FIG. 8.—Cyclic Stress-Strain Curves of Some Fiber Materials.
From G. Loasby, *Journal*, Textile Inst., Vol. 34, p. 52 (1943).

---

[14] F. D. Pilgrim, three unpublished reports to Subcommittee B-1 of A.S.T.M. Committee D-13 by Special Committee on Resilience (May 24, 1940; October 9, 1941; and March 5, 1942).

scribed this procedure for determining the recoverable strain and the recoverable work at various stresses. The curves in Fig. 9, which were published by Schramek and Hempel,[15] show the German method of plotting the results of the cyclic stress-strain test as the relation between the stress and the degree of elasticity. The *degree of elasticity* is the ratio of recoverable (elastic) strain to total strain at any given stress. It varies from one fiber material to another and, for each fiber material, it decreases as the stress increases.

The usefulness of the cyclic stress-strain curve for comparing the elastic properties of various fiber materials under a specified test procedure is illustrated in Loasby's paper on the mechanical behavior of nylon and other fibers.[16]

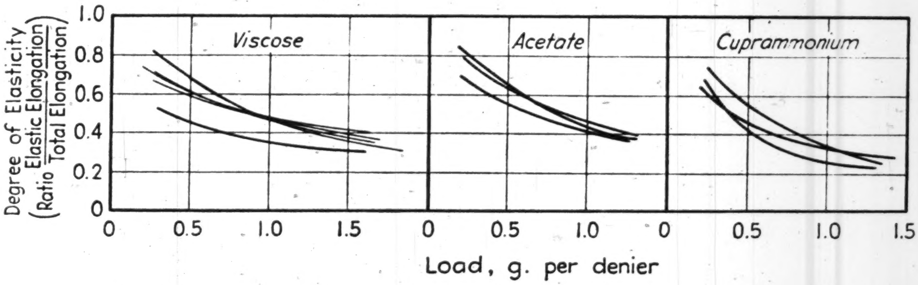


FIG. 9.—Relation Between Degree of Elasticity and Stress for Some German Rayon Staple Fibers (Schramek and Hempel).

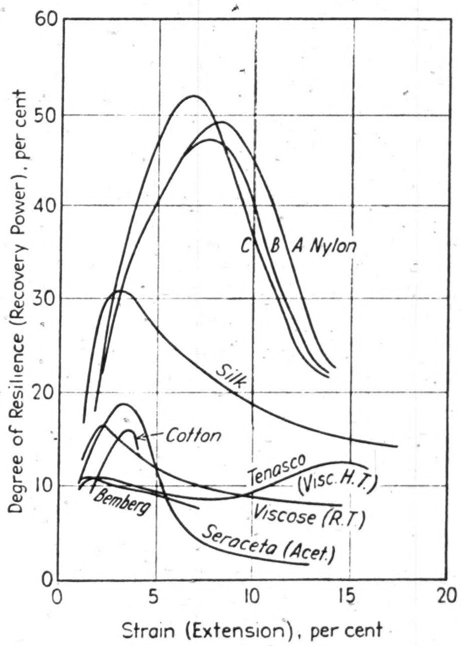


FIG. 10.—Relation Between Degree of Resilience and Strain for Some Fiber Materials.
From G. Loasby, *Journal*, Textile Inst., Vol. 34, p. 52 (1943).

Figure 10, taken from his paper, summarizes the results of an investigation of the degree of resilience (which he calls "recovery power") of a number of fiber materials at various strains. These data were obtained from load-recovery cycles made at a constant rate of loading of 4 g. per denier per min. The *degree of resilience* is the ratio of the area under the recovery part of the cyclic stress-strain curve (Fig. 8) to the area under the loading part of the curve. Figure 10 indicates that at strains of less than 3 per cent, the resilience of silk is superior to nylon and that below about 1.5 per cent strain, the resilience of silk, cotton, viscose, and acetate is probably better than nylon; whereas, above 3 per cent strain, the superiority of nylon's resilience over that of the other fibers increases rapidly. According to this chart, the maximum degree of resilience

---

[15] W. Schramek and F. Hempel, *Monatschrif'fuer Textilindustrie*, Vol. 53, p. 19 (1938).

[16] G. Loasby, *Journal of the Textile Institute*, Vol. 34, p. P-45 (1943).

(expressed as percentage) for each fiber, and the per cent strain at which it occurs, is as follows:

Nylon	50 per cent at	8 per cent strain
Silk	30 per cent at	3 per cent strain
Acetate	19 per cent at	3 per cent strain
Viscose R.T.	16 per cent at	2 per cent strain
Cotton	15 per cent at	4 per cent strain
Viscose H.T.	11 per cent at	14 per cent strain
Cuprammonium	10 per cent at	2 per cent strain

Another bit of interesting evidence on fiber properties can be obtained from some data on the tensile strength (breaking stress), modulus of rupture (toughness), and resilience, which are scattered through several tables in a book by H. Mark.[17] I have assembled these data (which are given in engineering units of kg. per sq. mm. for strength and kg. mm. per cu. mm. for toughness and resilience) in chart form in Fig. 11. I believe that the tests were made at rates of loading of the order of A.S.T.M. standard practice. The toughness and resilience of each fiber were determined at 60 per cent of its breaking stress P and computed to a unit volume basis. The values, therefore, represent breaking stress P, unit toughness W_{60}, and unit resilience R_{60} in engineering terms in our system.

A glance at this chart evokes a very marked respect for the mechanical stamina of silk which combines strength, toughness, and resilience in high degree. The sturdiness of wool, despite its low strength, is also very evident. Nylon is absent because these data antedate the advent of that fiber material. The data in this chart and in Fig. 10 supplement the P-S_a-W_i values which we have previously examined by providing some indication of the elastic part of the mechanical character of fiber materials.

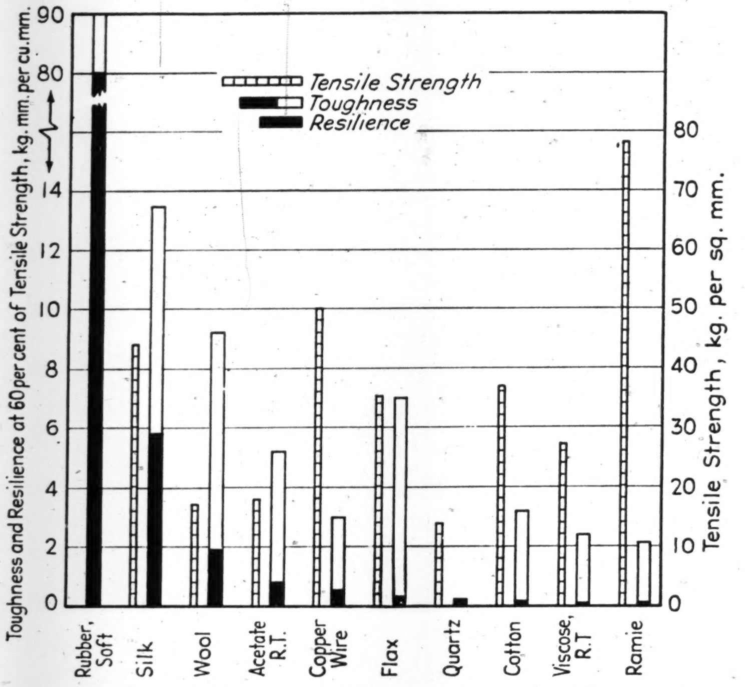


FIG. 11.—Strength, Toughness, and Resilience of Some Fiber Materials (Mark).

Because of the complex elastic-plastic

---

[17] H. Mark, *Die Physik und Chemie der Cellulose*, Julius Springer, Berlin (1932).

behavior of fiber materials which we have already mentioned, great caution should be exercised in extrapolating any data on elasticity or resilience from laboratory tests to predictions of performance-in-use or even in comparing elasticity and resilience data in one paper with that in another. In order to build up a dependable body of comparable data, there is an urgent need for the standardization of test methods for determining important criteria of fiber material character in accordance with some such system as is here proposed.

The Effect of Moisture, Heat, and Rate of Loading on the Mechanical Properties of Fiber Materials:

Thus far, we have simplified our discussion by confining our observations and calculations to data obtained under standardized conditions of relative humidity, temperature, and, for the most part, rate of loading. The promotion by Committee D-13 over a period of twenty-five years (as well as by other standardization and testing groups) of a standard atmosphere of 65 per cent relative humidity and 70 F. for the conditioning and testing of all textile materials has been invaluable to the industry; as has, also, the specification of 12 in. per min. for the speed of the pulling jaw of pendulum-type testing machines and 4 g. per denier per min. for the rate of loading of constant specimen-rate-of-load testing machines.

Adherence to these test conditions permits the comparison of data obtained in the same laboratory at different times and in different laboratories. It has contributed a great deal to the control of quality in the production of fibers, yarns, and fabrics and to the mutual understanding of seller, buyer, and consumer of all textiles whose value is based in part, or in whole, on mechanical properties.

Nevertheless, these test conditions are arbitrary and actually eliminate three of the variables which must be studied in order to predict the behavior of textile materials in the real world of changing temperature, moisture content, and loading conditions. Testing wet specimens, which is also specified in some cases, gives useful information on the maximum effect of moisture, but still fails to provide a working knowledge of the effect of varying atmospheric humidity on textile character.

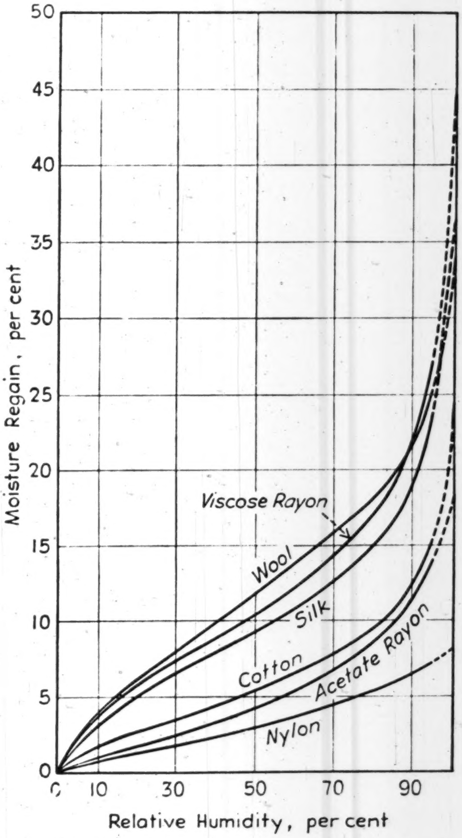


FIG. 12.—Moisture Absorption of Some Textile Fibers.

(*a*) *Effect of Moisture.*

All of the natural fibers and many of

TABLE XII.—THE EFFECT OF MOISTURE ON THE LATERAL SWELLING AND THE STRENGTH OF SOME FIBER MATERIALS.

Fiber Material	Moisture Regain, per cent		Swelling in Water, per cent increase in cross-sectional area from air dry to wet state	Wet Breaking Stress, per cent of value at 65% R.H.
	at 65% R.H.	at 100% R.H.		
Wool	14.7	33	32	80 to 90
Viscose R.T.	13.1	45	45	45 to 55
Silk	9.5	36	30	75 to 85
Cotton	7.0	25	44	110 to 120
Acetate R.T.	6.0	18	11	65 to 70
Nylon	4.1	8	slight	85 to 90
Vinyon	0	0	0	100

NOTE: The figures in the literature for regain at 100 per cent relative humidity and for swelling of cross section from air-dry to wet state vary considerably due chiefly to experimental difficulties. These data as given above are, therefore, approximate averages of the collected data except in the case of silk for which the regains and swelling values are based on a paper by A. C. Gcodings and L. H. Turl, *Journal*, Textile Inst., Vol. 31, p. T-69 (1940). The figures for regain at 65 per cent relative humidity and for change of strength from air-dry to wet state are founded on consistent published data.

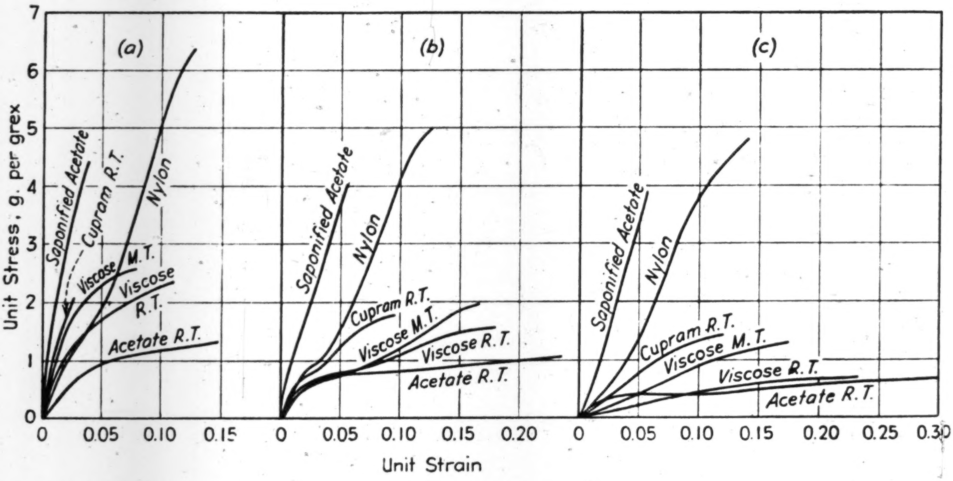


FIG. 13.—Stress-Strain Curves of Some Fiber Materials in an Atmosphere of 70 F.
(*a*) 0 per cent relative humidity.
(*b*) 65 per cent relative humidity.
(*c*) 100 per cent relative humidity.
Computed and plotted from data provided by Hindman and Fox.

the manufactured fibers are hygroscopic, absorbing moisture from or losing moisture to the surrounding air until equilibrium between fiber moisture and air moisture is reached. The moisture content of each hygroscopic fiber material is very sensitive to changes in the relative humidity of the surrounding air, and affects not merely the weight of the yarn or fabric, but also the dimensions of the fibers and all of the mechanical properties which we have been discussing.

The relation between relative humidity of air at 70 F. and moisture regain (moisture content as a percentage of the weight of dry material) for some textile fiber materials is shown in Fig. 12 based on data from various published sources. These curves show absorption, that is, the amount of moisture picked up from the dry side. An excellent study of the relation between relative humidity and moisture regain at elevated temperatures (96 to 302 F.) has been published by Wiegerink.[18]

The amount of absorbed moisture at 65 per cent and at 100 per cent relative humidity (wet) for a number of fiber materials is given in Table XII, which also indicates the lateral swelling and the change of strength produced by this difference in absorbed moisture. It is apparent from these data that there is no consistent relationship between any of the three factors, moisture pick-up, swelling, and strength, which can be applied generally to all fiber materials. Evidently, the molecular composition and structure of the material influence not only how much moisture is absorbed, but also how this absorption affects the swelling and the strength.

---

[18] J. G. Wiegerink, *Textile Research*, Vol. 10, p. 357 (1940).

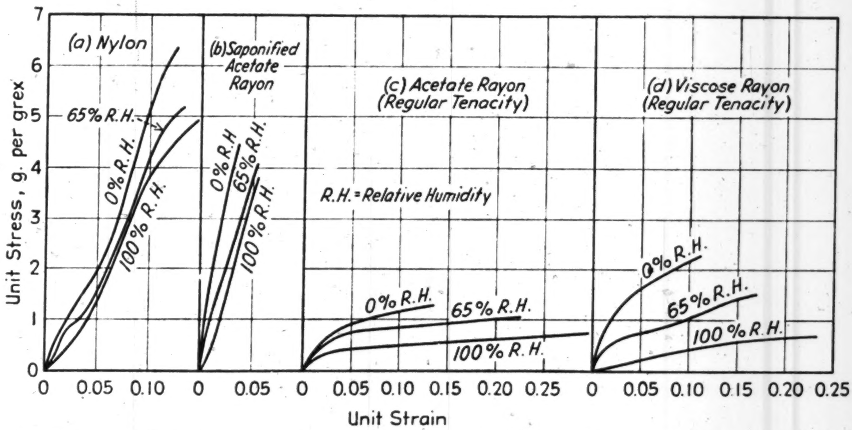
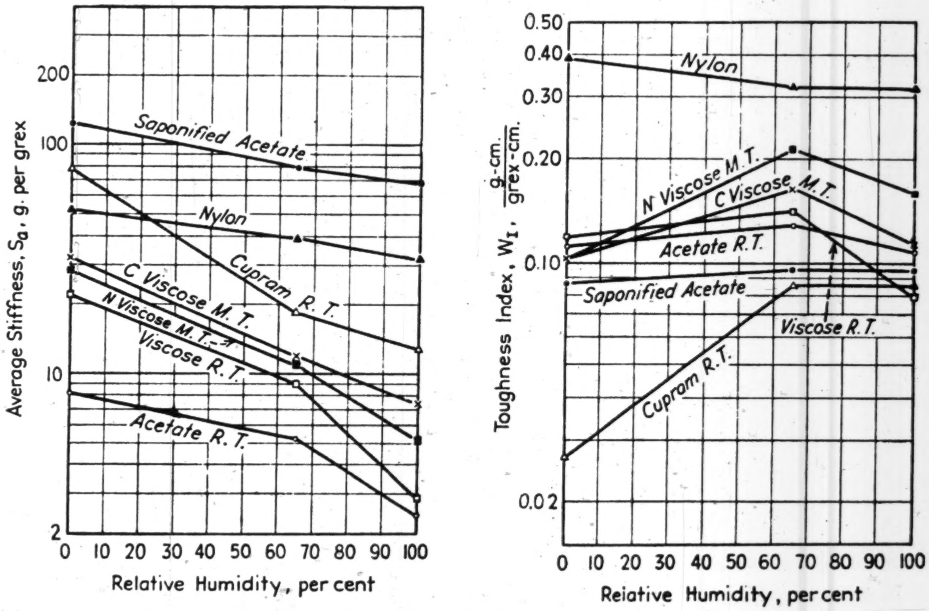


FIG. 14.—Effect of Relative Humidity on Stress-Strain Curves of Selected Fiber Materials from Fig. 13.



(*a*) Average stiffness *versus* relative humidity. (*b*) Toughness index *versus* relative humidity.

FIG. 15.—Effect of Humidity on Stiffness and Toughness.

From Hinkman and Fox data.

Comparatively few data on the effect of moisture on the stress-strain curves are available. Hindman and Fox, of the Textile Division at Massachusetts Institute of Technology, have conducted such a study on acetate rayon, cuprammonium rayon, nylon, and several types of viscose rayon.[19] Through the courtesy of these authors, I have obtained the detailed data on which their load-extension curves were based and have converted the loads to tenacity in terms of grams per grex and plotted the stress-strain curves. These experiments were not all made at the same rate of loading, but the rates were so low (ranging from 0.3 to 1.0 g. per grex per min.) that the differences should not prevent us from getting comparable information on the influence of moisture by a study of these curves (Fig. 13). At each of the three selected relative humidities, namely, 0 per cent, 65 per cent, and 100 per cent, the curve for a given fiber material has the form which is characteristic of that material.

Increasing relative humidity shifts the curves for all six fiber materials toward the strain axis, but the magnitude of the softening effect is different for each, being least for nylon and greatest for regular tenacity viscose. This is shown more clearly in Fig. 14, in which the curves for a given fiber are superimposed.

The effect of relative humidity on average stiffness S_a and on toughness index W_i is shown in Fig. 15, plotted on semilogarithmic coordinates so that equal vertical distances represent equal percentage changes. Figure 15 (*a*) shows that the order of average stiffness is the same at all humidities, except for cuprammonium rayon which is stiffer than nylon at 0 per cent relative humidity but less stiff at 65 and 100 per cent relative humidity. The average stiffness of nylon is least affected and that of regular viscose most affected by humidity changes. The rate of increase in pliancy is generally greater above than below 65 per cent relative humidity. Figure 15 (*b*) shows that the toughness index is much less sensitive to changes in relative humidity than is average stiffness. The viscose rayons appear to be tougher at 65 per cent relative humidity than at 0 or 100 per cent relative humidity. The toughness of nylon, regular tenacity acetate rayon, and saponified acetate rayon is relatively insensitive to moisture.

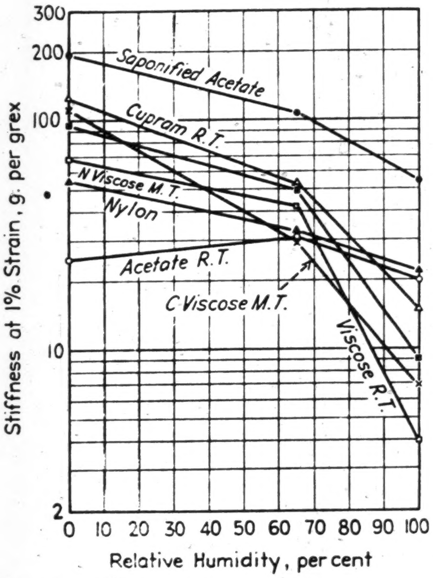


FIG. 16.—Stiffness at 1 per cent Strain *versus* Relative Humidity.

From the same data from which the curves in Fig. 13 were plotted, the stress, stiffness, and toughness, at 1 per cent strain, were calculated. If we assume that the yield point of all of these fibers is above 1 per cent strain, then the data tell us something about how the elastic stiffness and the resilience of these fiber materials at small deformations are affected by changes in relative humidity. Figure 16 shows the effect of relative humidity on the elastic stiffness at 1 per cent strain and reveals great differences in the sensitivity to moisture. Acetate rayon is least affected; viscose and cuprammonium rayons, the most. Nylon and saponified acetate occupy an intermediate position with respect to the softening influence of moisture on the elastic stiffness at small strains. It is clear that the order of elastic stiffness of the various fibers, as well as the magnitude of this criterion, changes with changing relative humidity.

---

[19] H. Hindman and K. R. Fox, "Effect of Relative Humidity on Load-Elongation Properties of Certain Fibers," *Rayon Textile Monthly*, Vol. 24, pp. 235 and 287 (1943).

Since for strain $e = 0.01$, $S_1 = 100\ p$, and $R_1 = 0.005\ p$; it follows that the effect of relative humidity on stress and on resilience at 1 per cent strain would also be indicated by Fig. 16 if the values of the ordinates were changed as indicated by the above relationships. In other words, stress, elastic stiffness, and elastic resilience, at 1 per cent strain, are all affected similarly by relative humidity but to a different degree.

At the risk of sounding repetitious, I think it well to point out that here again, as in the discussions of degree of elasticity and degree of resilience, the values of strength, stiffness, toughness, and resilience obtained from Hindman and Fox's data cannot be compared with other stress-strain data determined under different experimental conditions. Nevertheless, they do provide a valid way of learning something about the effect of relative humidity on the mechanical behavior of these fiber materials.

(*b*) *Effect of Heat.*

The textile fibers are, in general, far less sensitive to heat than to moisture, particularly within the range of climatic temperatures ordinarily encountered. A rule-of-thumb generalization states that a change of 10 F. in temperature is approximately equal to a 1 per cent change in relative humidity in its effect on the physical properties of textiles. The effect of increasing temperature is in the direction of decreasing strength and increasing elongation, that is, decreasing stiffness.

Fiber materials can be divided into two general classes with respect to the effect of heat—thermoplastic and nonthermoplastic. Acetate, vinyl, and nylon are typical examples of the first; silk, cotton, flax, and viscose, of the second.

The rate of change of the physical properties per degree rise in temperature is of the same order of magnitude for both types at ordinary temperatures, but, as the softening points of the thermoplastic materials are approached, they yield and begin to flow under load. This is the reason that excessive temperatures must be avoided in ironing acetate rayon, for example, to prevent shine, or glazing, or even destruction by melting. On the other hand, thermoplasticity makes possible the production of permanent moiré and other embossed patterns on fabrics of acetate rayon or nylon, permanent pleats and creases in garments of these materials, and preboarding or setting of acetate and of nylon hosiery. The softening points of thermoplastic textile fibers vary, ranging from that of the vinyl fibers, which be-

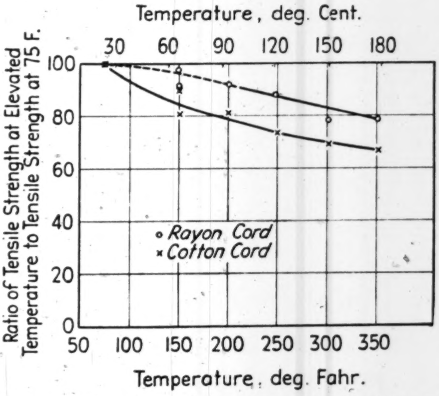


FIG. 17.—Effect of Temperature on the Tensile Strength of Cotton and Rayon Tire Cords.
From W. F. Busse, *Journal of Applied Physics*, Vol. 13, p. 715 (1942).

come sufficiently thermoplastic in the neighborhood of 150 F. to permit the internal tension which has been set up during manufacture of the fiber to cause a large contraction, to nylon, whose softening point is sufficiently high to permit its use in airplane tires. Acetate rayon falls between these two.

The effect of increasing temperature on nonthermoplastic fibers is generally proportional to the temperature up to the point where thermal decomposition or "tendering" begins. Figure 17, which is reproduced from a paper by Busse and co-workers, shows the effect of dry heat on the tensile strength of rayon and cotton tire cords.[20]

(*c*) *Effect of Rate of Loading.*

For all fibers, the breaking strength increases as the rate of application of the load increases. In general, the breaking elongation is much less sensitive to rate of loading. Peirce, in England, found that the elongation of single cotton fibers, cotton yarns, and rayon filaments remains fairly constant over a wide range of loading rates, whereas the strength increases with faster rates of loading.[21]

The lower limit of rate of loading is a constant load. A fiber will break in time under a constant load at a unit stress which is well below its breaking stress as determined at 4 g. per denier per min.

The upper limit of rate of loading is an instantaneous load which exceeds the breaking strength of the fiber. There is no laboratory technique for making such tests. Very high rates of loading can be attained by impact tests, that is, subjecting the fiber to the force of a weight traveling at high speed. Under the direction of E. R. Schwarz, the Textile Division of the Massachusetts Institute

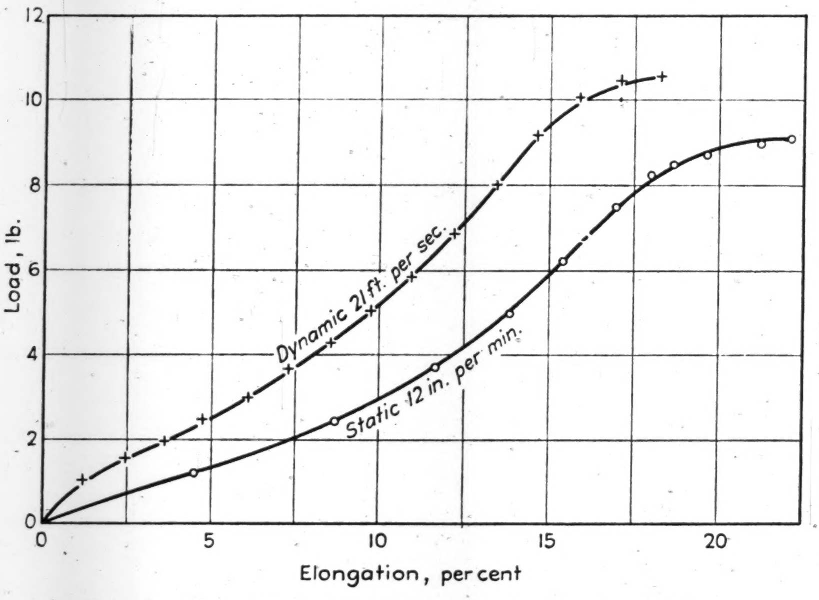


FIG. 18.—Effect of Rate of Loading on Tensile Behavior of Nylon.
From E. R. Schwarz, M.I.T. Textile Division.

---

[20] W. F. Busse, E. T. Lessig, D. L. Laughborough, and L. Larrick, "Fatigue of Fabrics," *Journal of Applied Physics*, Vol. 13, p. 715 (1942)

[21] F. T. Peirce, "Some Problems of Textile Testing," *Journal of the Textile Institute*, Vol. 18, p. T-475 (1927).

of Technology, in connection with a Slater Mills research program, has developed a recording impact tester which produces stress-strain curves of fibers or yarns broken at loading rates which cause rupture in less than 1/200 sec. The stress in the fiber is measured by the change in electrical resistance of a wire, the resistance of which is sensitive to tension. One end of the fiber is fixed to this wire and the other end to a bar which is struck by a falling weight whose movement is recorded by an oscillograph and camera in order to provide data on strain.

Figure 18, which was kindly provided by Prof. Schwarz, shows the effect of rate of loading on the load-elongation curve of nylon. Both curves were made on constant-rate-of-elongation machines developed at Massachusetts Institute of Technology under the Slater program. The lower curve was made at a rate of stretching of 12 in. per min. (0.017 ft. per sec.), which is of the order of usual textile testing speeds; and the upper curve, at 21 ft. per sec., which is an increase of 1200 times in the rate of loading. The slow, or normal, rate is referred to as a static test and the fast rate, as a dynamic test.

The total toughness of this nylon sample is approximately equal at both rates of loading but the dynamic breaking strength is 16 per cent greater than the static, and the dynamic average stiffness is 42 per cent greater than the static. As the elongation increases, the absolute difference between dynamic and static loads increases from about 1 lb. at 4 per cent elongation to a maximum of 3.5 lb. at 15 per cent elongation and then drops to 1.5 lb. at the break.

Expressed as percentage of the static load, the dynamic load and, therefore, the dynamic stress, dynamic average stiffness, and dynamic toughness drop rapidly from a maximum of 300 per cent at elongations of less than 1 per cent to 180 per cent at an elongation of 5 per cent, and then gradually to 128 per cent at the dynamic breaking elongation of 18 per cent.

The results of tests of all fiber materials in this machine will be awaited with interest.

THE INFLUENCE OF FIBER DIMENSIONS ON FIBER BEHAVIOR

We have examined in some detail the *influence of the fiber material* itself on the mechanical behavior of fibers. As has already been stated, the nature of the material of which a body is made is the first of three factors which affect the behavior of a body under the influence of external forces. The second and third are, respectively, the dimensions and the shape of the body. In general, for tensile forces acting on a beam or a fiber, the ultimate strength, the toughness, the limit of elastic load, and the resilience are each proportional to size and more or less independent of shape. Therefore, if the unit values of breaking stress, breaking strain, breaking toughness, yield stress, and yield resilience of a material are known, the breaking strength, breaking deformation, total toughness, yield load, and total resilience can be readily calculated for any size body, that is, for any size fiber. This is not strictly true of fibers, because a fiber is usually not a homogenous body. Dimensions, therefore, affect somewhat the unit values, as well as the ultimate values, of mechanical behavior.

Stiffness, on the other hand (which is of major importance in the subjective evaluation of textile hand and drape, as well as in the objective evaluation of many industrial textiles), is affected in a complex way by dimensions and by shape. Parenthetically, it should be pointed out that shearing and torsional behavior are also markedly affected by shape.

The dimensions of a body have a tremendous effect on its stiffness under the influences of bending and twisting forces. Torsion is actually a special and complicated type of shear and of flexure. For the sake of simplicity in treatment, let us, therefore, center our interest in the effect of fiber dimensions on the bending or deflection of a fiber. Engineering texts, such as the Mechanical Engineering Handbook, again point the way to a quantitative evaluation of this second factor in fiber behavior.

When a beam (or fiber) supported at one end is subjected to an external bending force F, acting at distance L from the point of support, it is bent (Fig. 19). The total amount of bending or flexure is measured by the deflection of the end of the beam from its original position. The degree of bending at a given point is defined by the radius of curvature C of the neutral axis of the beam. The radius of curvature at any point is

$$C = \frac{S_y I}{FL}$$

where:

S_y = elastic stiffness of the material, and
I = moment of inertia of the cross-section[22]

Hence, $F = \dfrac{S_y I}{CL}$

Thus, the load F at the end of a beam or fiber of given length L which is required to produce a given degree of bending (given radius of curvature C) is proportional to the product of S_y (the material stiffness which we have discussed above and I (which combines in itself the dimensional stiffness and the shape stiffness).

In order to examine the effect of dimensions alone on fiber stiffness, the effects of shape and of fiber material can be eliminated by confining our attention to a series of fibers composed of the same material, all of which have cross-sections of the same shape.

For a circular cross-section of diameter d,

$$F = \frac{\pi S_y}{64CL}\cdot d^4$$

Hence, for a cylindrical fiber of a given kind, the bending stiffness in terms of the force required to produce a given curvature in a given length is proportional to the fourth power of the diameter. Furthermore, since the grex number (or the denier) of a fiber of a given kind is proportional to the cross-sectional area (and, therefore, in the case of cylindrical fibers, to the square of the diameter), the bending stiffness is proportional to the square of the grex (or denier) of the fiber. Thus, doubling the grex of a fiber increases the bending stiffness four times, and doubling the diameter of a fiber increases the stiffness sixteen times.

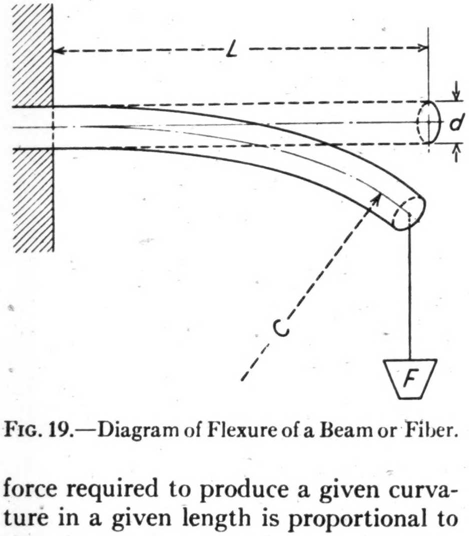


FIG. 19.—Diagram of Flexure of a Beam or Fiber.

---

[22] In the field of mechanics of materials, the concept "moment of inertia" I of a cross-sectional area with respect to the neutral axis of that section is defined as the limit of the sum of the product of the elementary areas into which the area may be conceived to be divided and the square of their distances from the given axis. The dimension of I is, therefore, the fourth power of a linear unit, as, for example, mm^4.

If S_y is expressed in kg. per sq. mm. and d, C, and L are expressed in millimeters, the bending stiffness of any cylindrical fiber in terms of bending force F can be computed in kilograms.

For our purpose, however, it is sufficient to examine Table XIII which lists a series of acetate rayon fibers ranging from 1.67 to 22.2 grex (1.5 to 20 denier) which are hypothetical in the sense that each is truly circular in cross-section. This table gives the diameter of each fiber in microns and the relative stiffness of each compared to the stiffness of the 5.55 grex (5 denier) fiber. The value of I for each fiber computed to mm.^{4} is also given. The 22.2 grex (20 denier) fiber is 16 times as stiff as the 5.55 grex fiber and almost 200 times as stiff as the 1.67 grex (1.5 denier) fiber.

Comparison of this range of *dimensional* stiffness with the range for the *inherent* stiffness of various fiber materials given in Fig. 5 indicates that both are of about the same order of magnitude, namely, several hundredfold. Thus, fiber fineness is as important as fiber material with respect to the stiffness of textile fibers and, consequently, of textile yarns and fabrics. In applying this fact to the problem of fabric design, however, it should be remembered that fiber bulk, or density, is closely interrelated with stiffness and other physical criteria in producing the subjective qualities of hand and drape in fabrics. Two fabrics of the same construction and composed of fibers of equal stiffness but of different fineness (because of a difference in fiber material density) would not have the same hand, drape, and visual texture, even if the mechanical properties of the two fiber materials were otherwise identical.

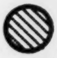
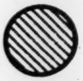
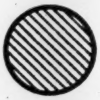
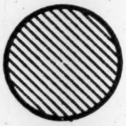
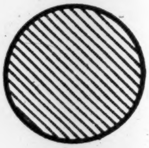
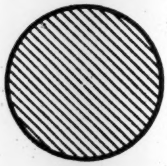
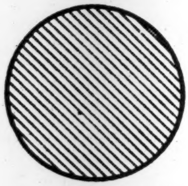
THE INFLUENCE OF FIBER SHAPE ON FIBER BEHAVIOR

In addition to the inherent material stiffness S_y and the dimensional stiffness, the shape of a body, such as a beam or a textile fiber, affects its behavior under the influence of external forces. The effect of shape of cross-section on the bending stiffness can be examined by calculating the moments of inertia I of a number of cross-sections of different shapes but of equal areas.

The first column in Table XIV illustrates the principal types of cross-sectional shape found in a sample of 5.55 grex (5 denier) dull acetate rayon staple fiber of the vintage of 1939, during an unpublished investigation of stiffness and other characteristics by W. F. Macia and me. These shapes were selected as typical of the range in a random assortment of one hundred fibers which were photographed and studied. The second column gives the ratio of major to minor axis for each actual section, as well as for two shapes which did not exist in the sample, namely, a true circle and a very thin rectangle.

From the various shapes of sections of structural beams treated mathematically in Mark's "Mechanical Engineering Handbook," shapes resembling the typical fiber sections were selected and are reproduced in the third column of Table XIV. The fourth column gives the dimensions of each beam section in microns for a cross-sectional area of 421 sq. microns which is the area of the cross-section of a 5.55 grex (5 denier) acetate rayon fiber. The fifth column gives the engineering formula for the moment of inertia I in terms of the dimensions of the various sections, and the sixth column, the computed moment of inertia for each section. The last column gives the relative stiffness of each shape about the axis indicated in the table, that is, the ratio of stiffness of each section to the stiffness of a circular section of the same area.

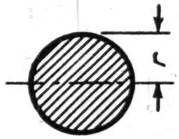
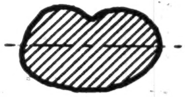
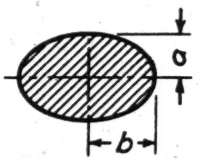
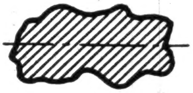
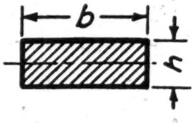
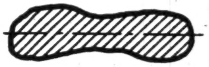
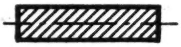
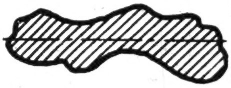
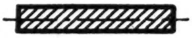
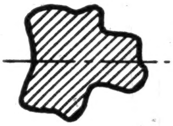
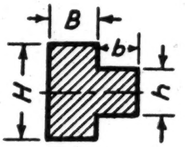
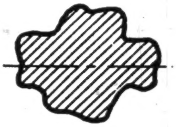
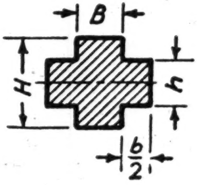
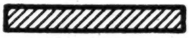
TABLE XIII.—EFFECT OF FIBER FINENESS ON BENDING STIFFNESS.[a]

Cross-Section (× 500)	Fineness		Diameter, microns	Moment of Inertia (I), mm.^{4} × 10^{-7} Formula $I = \frac{\pi d^4}{64}$	Relative Dimensional Stiffness (5.55 grex fiber = 1)
	grex	denier			
	1.67	1.5	12.7	0.012	0.085
	3.33	3.0	17.9	0.050	0.35
	5.55	5.0	23.2	0.142	1.0
	8.89	8.0	29.2	0.352	2.5
	13.3	12.0	35.8	0.807	5.7
	17.8	16.0	40.4	1.440	10
	22.2	20.0	46.3	2.250	16

---

[a] Although the data for diameter and for moment of inertia are computed for acetate rayon (density = 1.32) the relation between relative dimensional stiffness and fineness (in either grex or denier) as shown in this table holds for fibers of any one material.

TABLE XIV.—EFFECT OF FIBER SHAPE ON FIBER STIFFNESS.[a]

Types of Actual Sections of 5.55 grex (5 denier) Acetate Rayon Fibers: Shape	Types of Actual Sections of 5.55 grex (5 denier) Acetate Rayon Fibers: Ratio, Major Axis / Minor Axis	Beam Sections Resembling Actual Fiber Sections	Dimensions, microns	Moment of Inertia, I: Formulae	Moment of Inertia, I: Value, mm.^{4} $\times$ 10^{-7}	Relative Shape Stiffness (Circular 5.55 grex section = 1)
	1.0		$d = 23.20$	$\frac{\pi d^4}{64}$	0.142	1
	1.18		$a = 10.56$ $b = 12.67$	$\frac{\pi a^3 b}{4}$	0.117	0.82
	1.98		$h = 14.51$ $b = 29.02$	$\frac{bh^3}{12}$	0.074	0.52
	3.05		$h = 11.85$ $b = 35.55$	$\frac{bh^3}{12}$	0.049	0.34
	3.88		$h = 10.26$ $b = 41.04$	$\frac{bh^3}{12}$	0.037	0.26
	1.11		$h = 12.97$ $H = 25.94$ $b = 6.48$ $B = 12.97$	$\frac{BH^3 + bh^3}{12}$	0.200	1.41
	1.10		$h = 11.85$ $H = 23.70$ $b = 11.85$ $B = 11.85$	$\frac{BH^3 + bh^3}{12}$	0.148	1.04
	7.0		$h = 7.75$ $b = 54.25$	$\frac{bh^3}{12}$	0.021	0.15

---

[a] The data on dimensions and on moment of inertia are computed for a cross-sectional area of 421 sq. microns which is that of a 5.55 grex (5 denier) acetate fiber whose density is 1.32. However, the relation between relative shape stiffness and cross-sectional shape as shown in this table holds for fibers of any one material.

The results show that for three- and four-lobed sections and for ellipsoidal or two-lobed sections having axis ratios not greater than 1.2, the shape stiffness of each does not differ more than 50 per cent from that of a circular section or from one another.

Oblong or rectangular sections, however, decrease rapidly in stiffness as the axis ratio increases. In fact, the decrease in stiffness is inversely proportional to the axis ratio. For example, the flat, ribbon-shaped section pictured on the lowest line of Table XIV (which represents a special type of acetate rayon whose axis ratio is 7) has a stiffness only one seventh that of a circular section of the same area. The ribbon-shaped type of section is, furthermore, very ununiform in stiffness and will tend to bend only about its long axis.

The range of the shape stiffness for the wide variety of actual sections shown in Table XIV is less than sixfold as compared to two hundredfold each for the ranges of dimensional stiffness and of material stiffness which we have previously examined. The range of dimensional stiffness is, of course, not limited by the range of fineness which we have examined (1.67 to 22.2 grex) because finer fibers are made commercially in several of the manufactured varieties and, on the coarser side, there need be no limit to fiber size except that imposed by the suppleness desired in the textile structure.

Our excursion into the very important field of fiber stiffness indicates, therefore, that, within the limits of normal manufacturing control, cross-sectional shape is of little consequence to fiber stiffness (and, therefore, to the hand and drape of fabrics) as compared to the effects of fiber fineness and of the material of which the fiber is composed. In fact, since each kind of fiber as produced by nature or by man has a random variation of cross-sectional shape from fiber to fiber, the effect of shape on stiffness can be ignored and considerations of shape confined to its effect on other properties such as luster, abrasive wear, and interfiber friction, which are beyond the scope of this discussion.

CONCLUSION

In this lecture, I have attempted to fulfill a twofold purpose which falls, I believe, well within the objects for which the annual Edgar Marburg Lecture was established.

On the one hand, I have endeavored to provide the non-textile members of the Society with some information about textile fibers as engineering materials, not only in the sense of materials which might be used by them along with steel and wood and concrete to build a belt conveyer, an automobile, or a chemical factory, but also in the sense that the mechanical behavior of these tiny, microscopic beams which we call textile fibers is of primary importance alike to the strength of a hawser or a pneumatic tire, the comfort of an overcoat or of a summer suit, the utility of a carpet or a child's play dress, and the elegance and beauty of an evening gown.

On the other hand, I have tried to develop a framework for a systematic engineering approach to an understanding of textile fibers as structural materials and to inspire the textile mind, whether it be that of the designer, the fabricator, or the technologist, with the new philosophy of textiles which has been created by the advent of manufactured fibers.

The essence of this new philosophy is that fibers can be designed to meet specific textile wants rather than that textile wants must be designed to utilize immutable fiber "personalities."

This viewpoint gives a new perspective and variety to the textile scene. Textiles made of the thirty-odd natural and present-day manufactured fibers, which we have just examined, occupy the foreground. Beyond this foreground is the wide and exciting horizon of the future in which the only real limitations on the variety and the characteristics of textile fabrics yet unborn will be the ability of the textile designer and technologist to help the fiber maker to understand what kinds of fibers are wanted. This is an engineering job, for the engineer stands midway between the scientist and the craftsman. The latter has learned to know the natural fibers by generations of inherited, and years of first-hand experience. His knowledge is based on a subtle blend of direct sensory impressions and the results of routine test methods, many of which are rather empirical. The scientist, stimulated to investigate all textile fibers by the acceptance of his own inventions—fibers, plastics, and synthetic rubbers, which he groups along with the natural fibers and rubber under the general term, high polymers—has made great progress recently in understanding the molecular architecture of these materials and in explaining their mechanical behavior in terms of the strength of chemical bonds and other cohesive forces between the atoms and between the molecules.

The engineer, or the textile technologist with an engineering viewpoint, now has the opportunity and the responsibility of bringing the scientific knowledge about textile fibers down to earth in order to give the textile craftsman and technician the means of understanding and using such knowledge for the benefit of the industry and of the textile consumer.

There is a great deal to be said for the engineering approach to the translation of theories and experimental facts into the concrete reality of useful objects, such as industrial fabrics, household furnishings, and clothing; for the engineer's role in textiles, as in all other spheres of activity, is to catalyze the union of theoretical exactitude and practical reality by the liberal application of well-founded textile common sense.

APPENDIX A

PROPOSED RECOMMENDED UNIVERSAL YARN NUMBERING SYSTEM[1]

This is a proposed recommended practice and is published as information only. Comments are solicited and should be addressed to the American Society for Testing Materials, 260 S. Broad St., Philadelphia 2, Pa.

A universal yarn numbering system based on "Grex"[2] units is recommended for use with all fibers, on all sizes of yarns.

System.—The "Grex" Yarn Numbering System.

Unit.—The Grex, plural Grex, abbreviation Gx.

Definition.—The Grex number is defined as the weight in grams of 10,000 meters of yarn.

Supplementary Unit. — Kilogrex (Kgx.) = 1000 Gx.

1. Conversion factors for length and weight:

Yards × 0.914 = meters
Ounces × 28.35 = grams
Grains × 0.065 = grams

2. Conversion factors for reciprocal (length per unit weight) numbering systems:

Grex = 3 100.3 ÷ woolen run number (1600 yd.)
= 4 960.5 ÷ typp number (1000 yd.)
= 5 905.4 ÷ cotton hank number (840 yd.)
= 8 858.1 ÷ worsted hank number (560 yd.)
= 10 000.0 ÷ metric number (496 yd.)
= 16 535.1 ÷ linen lea number (300 yd.)
= 16 535.1 ÷ woolen cut number (300 yd.)

To convert grex to the corresponding units, divide the numerical constants given above by the grex number.

3. Conversion factors for direct (weight per unit length) numbering systems:

Grex = 1.111 × denier—grams per 9,000 m. (0.90)
= 344.5 × spyndle—pounds per 14,400 yd. (0.0029)
= 5.905 × grains per 120 yd. (0.1693)
= 7.086 × grains per 100 yd. (0.1411)
= 19.377 × drams per 1000 yd. (0.0516)
= 4.961 × pounds per 1,000,000 yd. (0.2015)
= 31.00 × ounces per 10 yd. (323)

To convert grex units to other units, divide the Grex by the constants given; thus, denier = grex ÷ 1.11, or multiply by their reciprocals shown in parentheses; thus, denier = 0.90 × grex.

4. The yards per pound of a 1.0 grex yarn = 4,960,537.2.

---

[1] This proposed recommended practice is under the jurisdiction of the A.S.T.M. Committee D-13 on Textile Materials. Published as information in October, 1944.

[2] Derived from GRams pEr 10,000 meters
GR.....E..X

APPENDIX B

SYMBOLS AND ABBREVIATIONS

A = area of cross-section
b = width (or breadth)
C = radius of curvature of beam or fiber
cm. = centimeter
D.E. = degree of elasticity
D.R. = degree of resilience
d = diameter
den. = denier, a unit of fineness (g. per 9000 m.)
e = unit strain (extension) = unit elongation, the ratio of elongation to original length of specimen
e_y = unit strain at yield point (yield strain)
e_p = unit strain at load p
e_r = residual unit strain after cessation of stress
E = unit breaking strain
f = fineness = linear density, the mass of a given length of material of uniform cross-section along its length
F = force or load
F_u = breaking force or load
g. = gram
gx. = grex, a unit of fineness (g. per 10,000 m.)
h = height (or depth)
H.I. = high impact, a designation for a class of rayons
H.T. = high tenacity, a designation for a class of rayons
I = moment of inertia of the cross-section of a beam or fiber
L = original length
l = deformation (elongation)
M = mass
m. = meter
mm. = millimeter
min. = minute
M.T. = medium tenacity, a designation for a class of rayons
o = origin of stress-strain curve
psi. = pounds per square inch
p = unit stress (load per unit cross-section) or tenacity (load per unit fineness)
p_y = stress or tenacity at yield point (yield stress)
p_e = stress or tenacity at unit strain e
P = unit breaking stress or breaking tenacity
R = unit resilience, recoverable work per unit volume (or per unit fineness) of material
R_y = unit yield resilience, maximum recoverable work per unit volume (or per unit fineness) of material
R.T. = regular tenacity, a designation for a class of rayons
S = stiffness, ratio of unit stress to unit strain
S_y = elastic stiffness, stiffness to yield point
S_a = average stiffness, ratio of breaking stress to breaking strain
u = breaking point
V = volume
W_u = unit breaking toughness
W_e = unit toughness to strain e
W_p = unit toughness to stress p
W_i = toughness index
x = proportional limit
y = yield point

APPENDIX C

DERIVATION OF FORMULAS AND DIMENSIONS IN TABLES IX AND X*

Strength:

When an external force (in this case a pull, or tensile force) acts on one end of a body whose other end is immovably fixed, internal forces (in this case tension) equal to the external forces occur to oppose or resist the external force. The sum of these forces in any section is equal to the total force. The strength of a body (in tension) is equal to the total of the forces in the entire cross-section of the body at the instant it breaks at that cross-section.

Breaking Stress P.—In studying the strength of the *material* of which a body is composed, strength is expressed in terms of unit stress, that is, force per unit cross-section. If a force or load F_u is required to break a rod of material, the area of whose cross-section is A, then

$$\textit{breaking stress } P = \frac{F_u}{A} \ldots\ldots (1)$$

In engineering terms, if F_u is expressed in kilograms and A in square millimeters, then the dimension of the quantity, *breaking stress*, is kg./mm².

In textile terms, unit stress is usually expressed as stress per unit fineness (linear density) f, rather than as stress per unit cross-section, and unit stress based on fineness is called *tenacity*. Thus

$$\textit{breaking tenacity } P = \frac{F_u}{f} \ldots . (2)$$

If F_u is expressed in grams and f in denier, then the dimension of the quantity, *breaking tenacity*, is g./den. If f is expressed in grex (see Appendix A), then the dimension of the quantity, *breaking tenacity* is g./gx.

Stress (Tenacity) at Any Strain e.—The unit stress p_e at any strain e below the breaking strain (see below) is computed by the same formulae and in the same dimensions as the breaking stress (breaking tenacity), except that the breaking force F_u is replaced by the force F_e required to produce the given strain e. Thus

$$p_e = \frac{F_e}{A} \ldots\ldots\ldots\ldots (3)$$

and

$$p_e = \frac{F_e}{f} \ldots\ldots\ldots\ldots (4)$$

Elongation:

Although a body which is immovably fixed at one end and subjected to the action of a pull, or external tensile force, at the other end develops internal forces which oppose and equal the external force, its shape is deformed by the external force. The major deformation is an elongation, or extension of length, although some reduction in cross-section also occurs.

Breaking Strain.—In studying the elongation of the *material* of which a body is composed, elongation is expressed in terms of either unit strain or of percentage strain. Unit strain is the elongation per unit length of the material. Percentage strain is equal to unit strain × 100. In textile literature, strain is expressed sometimes one way and sometimes the other. Care must therefore be exercised in reading or using strain (elongation) data in order to avoid confusion. Unit strain is more convenient mathematically and is used throughout this lecture except where percentage strain is definitely stated.

If the elongation of a rod of length L is l_u at the instant it breaks under the influence of a tensile force F_u, then,

$$\text{unit breaking strain } E = \frac{l_u}{L} \ldots (5)$$

Since E is a ratio of length to length, it has no physical dimension.

Strain at Any Stress p.—The strain e_p at any stress p below the breaking stress is computed by the same formula as the breaking strain, except that the breaking elongation l_u is replaced by the elongation l_p which is produced by the given stress p. Thus:

---

* The presentation and, therefore, the responsibility for this appendix on derivations is entirely mine, but I am indebted to Dr. H. F. Schiefer, senior physicist in the Textile Section of the National Bureau of Standards, for his kindness in perusing it and providing me with some clarifying suggestions.

$$e_p = \frac{l_p}{L} \ldots\ldots\ldots\ldots (6)$$

Stiffness:

The quality, stiffness, is the ability to resist deformation. In the case of a body subjected to a tensile force, or pull, stiffness is the ability to resist elongation under the influence of such a force. The quantitative measure of stiffness of a body under tension is the amount of force required to produce a unit of elongation. In studying the stiffness of the *material* of which a body is composed, force is expressed in terms of unit stress and elongation in terms of unit strain. I propose the following three criteria of stiffness for evaluating *materials* for textile fibers:

Average Stiffness S_a.—Average stiffness is the over-all stiffness of a material from its original state to its breaking point. It is computed as the ratio of unit breaking stress P to unit breaking strain E and thus indicates the average stress (or tenacity) for the entire range of extensibility of the material per unit increase in strain. Thus:

$$S_a = \frac{P}{E} \ldots\ldots\ldots\ldots (7)$$

Average stiffness is useful as a criterion of a material's general character because it can be computed, without recourse to the stress-strain curve, from the widely used determination of breaking strength and elongation, provided the cross-sectional area of the specimen or the fineness (denier, grex, etc.) is known. It is an indicator of general character with respect to the quality of stiffness.

Since E is dimensionless, the mathematical dimension of S_a is the same as that of P, namely, kg./mm.^{2} in engineering terms, and g./gx. in textile terms. On the stress-strain chart it is represented by the slope of the straight line o–u (Fig. 4) joining the origin and the breaking point. Average stiffness may be thought of as the average stress per percentage elongation × 100.

Elastic Stiffness.—The elastic stiffness S_y is the stiffness of the material within its elastic limit or yield point y. It is indicated by the slope of the stress-strain curve (Fig. 4) between the origin o and the yield point y (or of the straight line joining o and y if the actual curve is not linear between o and y) and is computed thus,

$$S_y = \frac{P_y}{e_y} \ldots\ldots\ldots\ldots (8)$$

Its dimension is kg./mm.^{2} or g./gx., as in the case of average stiffness.

For metals and other substances which have a sharply defined elastic limit marked by a definite yield point on the stress-strain curve, the elastic stiffness is readily determined from the curve. In engineering and scientific terminology, elastic stiffness is called modulus of elasticity, or Young's modulus (after the name of the person who proposed its use). Its dimensions are the same as those for stiffness.

Because the high polymeric materials of which most textile fibers are made exhibit a combination of plastic and elastic behavior under stress, there is no sharply defined elastic limit. The location and even the occurrence of a yield point on the stress-strain curve is dependent on the test conditions. Therefore, in studying the stiffness of fiber materials under small stresses or strains, that is, in the range of loads and elongations to which the fiber materials are subjected during the draping, bending, and tensions of ordinary wear and use, it is convenient to compare the stiffness of different fiber materials to any arbitrarily chosen stress or strain such as to 0.1 g./gx. or 0.5 g./gx. etc., or to 1 per cent elongation (0.01 strain) or 2 per cent elongation (0.02 strain), etc.

Stiffness to Any Stress p.—The stiffness S_p to any given stress p is computed as follows:

$$S_p = \frac{p}{e_p} \ldots\ldots\ldots\ldots (9)$$

Stiffness to Any Strain e.—The stiffness S_e to any given strain e is computed thus:

$$S_e = \frac{p_e}{e} \ldots\ldots\ldots\ldots (10)$$

If p is expressed in kg./mm.^{2} or in g./gx., then the dimension of S_p and S_e is also kg./mm.^{2} or g./gx., as in the case of average stiffness and elastic stiffness.

Toughness:

The quality, toughness, is the ability to absorb work. The quantitative measure of work is the product of force times the distance through which the force acts.

Thus, Work $= F\cdot l$.

If a body, such as a rod, is subjected to a steadily increasing tensile force, or pull, it will be deformed, the major deformation being a lengthening along the line of the pulling force. Each value of the increasing force F produces a small increment of elongation Δl, hence the increment of work absorbed is equal to $F\cdot\Delta l$. The summation of all these increments of absorbed work between $l = o$ and $l = l_u$ (the elongation at the breaking point) equals the total work required to rupture the rod, and can be computed from the expression,

$$\text{Total toughness (work of rupture) } W = \int_0^{l_u} F\,dl.$$

If F is expressed in kilograms and l in millimeters, the dimension of the work of rupture is kg.·mm.

If the elongation in units of length (such as millimeters) is plotted for each value of the load in units of force (such as kilograms) on rectangular coordinate paper, the resulting line is the load-elongation curve and the area under this curve in terms of these units is a measure of the work absorbed in extending the body to the breaking point.

In studying the *material* of which a body such as a textile fiber is composed, I suggest that modifications of the term, toughness, be employed for several useful quantitative criteria of the quality, toughness, by computing the work absorbed per unit volume V of material in the case of engineering units, and per unit fineness f per unit length (that is, per unit mass) of material in the case of textile units, as follows:

Toughness Index W_i.—The toughness index is the work per unit volume (or per unit mass) of material which would cause rupture if the load-elongation curve were a straight line joining the origin o and the breaking point u. It is useful as a criterion of a material's general character with respect to toughness because it can be computed without recourse to the actual load-elongation, or stress-strain, curve from the widely used determination of breaking strength and elongation, provided that the cross-sectional area and the gage length of the specimen, or the fineness of the specimen (denier, grex, etc.) are known.

Thus, in engineering terms, if F is expressed in kilograms, l in millimeters, and V in cubic millimeters, the area under the straight line is $\frac{1}{2}F_u l_u$ and the derivation of the formula for the toughness index and of its dimensions is as follows:

$$W_i = \frac{1}{2}\cdot\frac{F_u l_u}{V} \qquad \frac{\text{kg.mm.}}{\text{mm.}^3}$$

but

$$V = AL$$

hence

$$W_i = \frac{1}{2}\cdot\frac{F_u l_u}{AL} \qquad \frac{\text{kg.mm.}}{\text{mm.}^2\,\text{mm.}}$$

but

$$\frac{F_u}{A} = P \qquad \frac{\text{kg.}}{\text{mm.}^2}$$

hence

$$W_i = \frac{1}{2}\cdot\frac{Pl_u}{L} \qquad \frac{\text{kg.}}{\text{mm.}^2}\cdot\frac{\text{mm.}}{\text{mm.}}$$

but

$$\frac{l_u}{L} = E \quad \text{or} \quad l_u = EL$$

hence

$$W_i = \frac{PE}{2}\cdot\frac{L}{L} = \frac{PE}{2} \ldots\ldots (11)$$

$$\frac{\text{kg.}}{\text{mm.}^2}\cdot\frac{\text{mm.}}{\text{mm.}} = \frac{\text{kg.mm.}}{\text{mm.}^3} = \frac{\text{kg.}}{\text{mm.}^2}$$

Although unit toughness quantities are often expressed in terms of the net dimension, unit stress, it will be noted from this detailed derivation that they should always be thought of in their true significance of "absorbed work per unit volume (or mass) of material."

In textile terms, the toughness index can be expressed as work per unit fineness per unit length of material instead of per unit volume of material. This corresponds to work per unit mass of material. If F_u is expressed in grams, l_u in centimeters, and f in grex, then

$$W_i = \frac{1}{2} \cdot \frac{F_u l_u}{fL}. \qquad \frac{\text{g.cm.}}{\text{gx.}}$$

but $$\frac{F_u}{f} = P \qquad \frac{\text{g.}}{\text{gx.}}$$

and $$\frac{l_u}{L} = E \qquad \frac{\text{cm.}}{\text{cm.}}$$

therefore $$W_i = \frac{1}{2} PE \ldots\ldots\ldots (12)$$

$$\frac{\text{g.cm.}}{\text{gx.cm.}} = \frac{\text{g.}}{\text{gx.}}$$

Breaking Toughness W_u.—The breaking toughness is the actual work per unit volume (or per unit mass) of material which is required to rupture the material, and is measured by the area under the stress-strain curve from the origin *o* to the breaking point *u*.

The derivations are analagous to those for toughness index above, and result in integral expressions. Thus, in both engineering and textile terms,

$$W_i = \frac{PE}{2}$$

becomes $$W_u = \int_0^E p\,de \ldots\ldots (13)$$

$$\frac{\text{kg.mm.}}{\text{mm.}^3} = \frac{\text{kg.}}{\text{mm.}^2} \text{ or } \frac{\text{g.cm.}}{\text{gx.cm.}} = \frac{\text{g.}}{\text{gx.}}$$

Toughness to Any Stress p.—The toughness to any stress p is the work required per unit volume (or per unit mass) to produce the stress p in the material (see also resilience).

In both engineering and textile terms,

$$W_p = \int_0^{e_p} p\,de \ldots\ldots (14)$$

$$\frac{\text{kg.mm.}}{\text{mm.}^3} = \frac{\text{kg.}}{\text{mm.}^2} \text{ or } \frac{\text{g.cm.}}{\text{gx.cm.}} = \frac{\text{g.}}{\text{gx.}}$$

Elasticity:

The quality, elasticity, is the ability of a body to recover its original shape or dimensions in full or in part upon cessation of the force or forces which have deformed it. In the case of a body subjected to a tensile force, or pull, which produces an elongation, elasticity is the ability of the body to contract to or toward its original length when the force ceases to act.

In the field of engineering, the usual quantitative measure of the elasticity of a body with respect to tensile force is the force, or load, which the body can withstand without suffering any permanent deformation.

In studying the elasticity of the *material* of which a body is composed, force is expressed in terms of stress and elongation in terms of strain as before.

The elastic limit is usually expressed in terms of the *yield stress* p_y which is the stress at the yield point *y*. Thus, in engineering terms

$$p_y = \frac{F_y}{A} \ldots\ldots\ldots (15)$$

If F_y is expressed in kilograms and A in square millimeters, the dimension of P_y is $\frac{\text{kg.}}{\text{mm.}^2}$.

In textile terms

$$p_y = \frac{F_y}{f} \ldots\ldots\ldots (16)$$

If F_y is expressed in grams and f in grex, the dimension of p_y is $\frac{\text{g.}}{\text{gx.}}$.

If recoverable elongation is to be considered, rather than recoverable load, the elastic limit can be expressed in terms of the yield strain e_y which is the strain at the yield point *y*. Thus,

$$e_y = \frac{l_y}{L} \ldots\ldots\ldots (17)$$

Regardless of the unit used to express l_y and L, E_y is dimensionless.

The yield stress and yield strain represent the limit within which the material is completely elastic. An equally valid criterion of elasticity which is useful in materials such as textile fibers, which exhibit partial elastic recovery when stressed beyond the elastic limit is the *degree of elasticity*, D.E., which is the ratio of recoverable strain to total strain at any given stress (or at any given strain). Thus, if a material is subjected to a stress p which produces a strain e and, upon removal of the stress, the material contracts partially to a residual strain e_r at zero stress, then the recoverable (elastic) strain is $e - e_r$ and the degree of elasticity is

$$\text{D.E.} = \frac{e - e_r}{e} \quad \ldots\ldots (18)$$

D.E. is dimensionless.

Resilience:

The quality, resilience, is the ability to absorb work without suffering permanent deformation or, put in another way, the ability to perform work by complete or partial recovery from deformation upon cessation of the deforming force. The quantitative measure of work is, as already stated, the product of force times the distance through which the force acts. The derivation of formulae and dimensions for resilience is analagous to that developed in the section above on toughness, since resilience is, in fact, elastic toughness, that is, recoverable toughness.

By analagous reasoning, the following formulae and dimensions for criteria of resilience can be derived:

The *unit yield resilience* R_y is the work, per unit volume (or per unit fineness) of material, which is required to deform the material to its yield point (elastic limit) and which is completely recoverable. Since the stress-strain curve is essentially a straight line from its origin to the yield point,

$$R_y = \frac{p_y e_y}{2} \quad \ldots\ldots\ldots (19)$$

In the engineering units and textile units used heretofore, the dimension of R_y is $\frac{\text{kg.}}{\text{mm.}^2}$ and $\frac{\text{g.}}{\text{gx.}}$, respectively. If the recovery part of the cyclic stress-strain curve is not a straight line, the exact expression for unit resilience is $\int_{e_r}^{e} p'\,de$, where p' is the stress on the recovery curve. The dimensions are the same as for toughness, namely, $\frac{\text{kg.mm.}}{\text{mm.}^3} = \frac{\text{kg.}}{\text{mm.}^2}$ in engineering terms, and and $\frac{\text{g.cm.}}{\text{gx.cm.}} = \frac{\text{g.}}{\text{gx.}}$ in textile terms. Thus, the *unit resilience at any stress p, R_p* is

$$R_p = \int_{e_r}^{e_p} p'\,de \quad \ldots\ldots (20)$$

and the unit resilience at any strain e, R_e is

$$R_e = \int_{e_r}^{e} p'\,de \quad \ldots\ldots (21)$$

If $e_r = o$, the material is completely resilient at stress p. If e_r is greater than zero, the material is not completely elastic and, therefore, not completely resilient. In either case, the formula (whose value is equal to the area under the *recovery* part of the cyclic stress-strain curve) gives the unit resilience at stress p or at strain e.

The *degree of resilience* D.R. is the ratio of recoverable work to total work at any stress p or at any strain e. Thus,

$$\text{D.R.}_p = \frac{\int_{e_r}^{e_p} p'\,de}{\int_{0}^{e_p} p\,de} \quad \ldots\ldots (22)$$

and

$$\text{D.R.}_e = \frac{\int_{e_r}^{e} p'\,de}{\int_{0}^{e} p\,de} \quad \ldots\ldots (23)$$

Because it is a ratio, D.R. is dimensionless.

THE TECHNICAL COHESIVE STRENGTH OF SOME STEELS AND LIGHT ALLOYS AT LOW TEMPERATURES

By D. J. McAdam, Jr.,[1] R. W. Mebs,[1] and G. W. Geil[1]

Synopsis

An investigation has been made of the technical cohesive strength of a high-carbon steel, a stainless steel, duralumin, and magnesium alloys. Tension tests of notched and unnotched specimens have been made at room temperature and at selected low temperatures down to that of liquid air. Diagrams have been constructed to show the influence of notch depth, notch angle, and root radius on strength and ductility. A study is thus made of the influence of the ratio of radial to axial stress on the technical cohesion limit and the influence of plastic deformation, heat treatment, and temperature on technical cohesive strength. Diagrams are also included to show the quantitative variation of strength and ductility with temperature.

The technical cohesive strength of metals has been discussed in three papers by one of the authors (**4**, **5**, **6**);[2] the discussion was based on data found in the literature. In more recent papers (**7**, **8**), two of the authors have presented data obtained in their own experiments, which involved tension tests of notched specimens. The metals considered in those papers have high ductility, at least when tested at room temperature in the form of unnotched specimens. The present paper gives results obtained with less ductile metals, including high-carbon steels and light alloys, and also gives additional results obtained with one of the previously discussed metals (13 per cent chromium, 2 per cent nickel steel). Because of the lesser ductility, it has been found necessary to include experiments with larger notch-root radii than those used in the previously described experiments, and to make a more through study of the influence of the root radius on the strength and ductility of notched specimens.

As shown in the previous papers (**4** to **8**), the technical cohesive strength of a metal, in any particular state as regards prior mechanical treatment and heat treatment, cannot be represented by single stress value. The *technical cohesive strength* comprises an infinite number of *technical cohesion limits*, each corresponding to a specific combination of the principal stresses.[3] The technical cohesive strength of a metal, therefore, must be represented by a diagram consisting of curves of variation of the cohesion limit with variation of the stress system. Such diagrams of various types have been presented in previous papers, and consideration has also been given to the variation of the technical cohesive strength with plastic deformation and with temperature.

---

[1] National Bureau of Standards, Washington, D. C.

[2] The boldface numbers in parentheses refer to the reports and papers appearing in the list of references appended to this paper, see p. 605.

[3] Any stress system may be resolved into three principal stresses normal to three mutually perpendicular planes, known as the "principal planes," on which there is no shear. Tensile stresses are viewed as positive, and compressive stresses are viewed as negative. In this paper as in the previous papers, the algebraically greatest principal stress is designated S_1, the least principal stress is designated S_3, and the intermediate principal stress is designated S_2.

METHOD OF INVESTIGATION, SPECIMENS, AND MATERIALS

The method of investigation of the technical cohesive strength is based on the fact that when a notched cylindrical specimen is subjected to longitudinal tension, the minimum cross-section is under transverse radial tension. The mean radial stress tends to increase with the depth and sharpness of the notch, but is always less than the longitudinal stress. The algebraically greatest principal stress (S_1), therefore, is longitudinal. The radial stress is equivalent to two equal principal stresses (S_3) which are rotatable without change around the axis of the specimen. By the use of notched specimens, therefore, it is possible to investigate the influence of the radial stress ratio (S_3/S_1) on the technical cohesion limit, ultimate stress, yield stress, and ductility. One of the previous papers (7) gives results so obtained with both shallow and deep notches. In the present paper, attention is confined almost entirely to the influence of deep notches. With such notches the disturbing effects of stress concentration are minimized, and thus do not interfere with a study of the influence of the radial stress ratio (7, 8).

Most of the notched specimens were approximately 6 in. in length; those having large angles were necessarily somewhat longer. The ends of most specimens were threaded to $\frac{3}{4}$ in. in diameter. Between the threaded ends, each specimen was machined to a selected uniform diameter and a circumferential V notch of fixed angle, depth, and root radius was machined at the mid-section. The notch radius was carefully machined so that the conical sides of the notch were tangent to the arc at the root. Care was also taken to avoid heating, bending, or appreciable cold working during machining.

TABLE I.—DESCRIPTION OF METALS.

Metal	Designation	Condition	Original Rod Diameter, in.	Chemical Composition, per cent												
				Carbon	Iron	Nickel	Copper	Chromium	Aluminum	Magnesium	Silver	Manganese	Zinc	Phosphorus	Sulfur	Silicon
13 per cent chromium, 2 per cent nickel steel	E	Annealed	0.875	0.09	diff.	2.06	....	13.3	....	....	....	0.48	..	....	....	0.26
0.73 per cent carbon steel	V	Hot rolled	1.125	0.73	diff.	....	....	....	....	....	....	0.31	..	0.019	0.017	0.24
Duralumin, type 24S-T	DA	As aged	0.750	....	....	....	4.5	....	diff.	1.5	....	0.6	....	....	....	....
Magnesium alloy, A.S.T.M. No. 8X, first heat	MJ	Extruded	0.745	....	<0.005	<0.005	<0.05	....	6.5	diff.	....	0.2	1.0	....	....	<0.3
Magnesium alloy, A.S.T.M. No. 8X, second heat	MK	Extruded	0.750	....	<0.005	<0.005	<0.05	....	6.5	diff.	....	0.2	1.0	....	....	<0.3
Magnesium alloy, A.S.T.M. No. 18X	MF	Extruded	1.00	....	<0.005	<0.005	<0.05	....	2.7	diff.	....	0.3	1.0	....	....	<0.3
Experimental magnesium alloy	MX	Extruded	0.75	....	<0.005	<0.005	<0.05	....	2.7	diff.	5.8	0.2	2.7	....	....	....

Before testing, each specimen was carefully measured as follows: the maximum diameter was measured by micrometer calipers; the diameter of the minimum section, at two or more positions

TABLE II.—HEAT TREATMENT OF THE STEELS.

Material	Designation	Temperature, deg. Fahr.	Time Held, hr.	Cooled in	Temperature, deg. Fahr.	Time Held, hr.	Cooled in
13 per cent chromium, 2 per cent nickel steel	E	1240[a]	....	Furnace	....	....	....
0.73 per cent carbon steel	V—14.5	1450	1	Furnace	....	....	....
	V—0-10	1450	1	Oil	1000	2	Air

[a] Heat treated by manufacturer.

uniformly spaced circumferentially, was determined by means of a measuring microscope. The root radius was measured by means of a graduated set of wires of slightly different diameters, and the notch angle was measured on a magnified photograph of the notched specimen.

The metals used were a 0.73 per cent carbon steel, a steel containing 13 per cent chromium and 2 per cent nickel, a sample of duralumin of type Al 24 (hereafter referred to in this paper as duralumin), and several magnesium alloys. The 0.73 per cent carbon steel was tested both in the fully annealed and in the heat-treated condition. To study the influence of plastic deformation on the technical cohesive strength and to reveal more clearly the influence of the radial stress ratio on the technical cohesion limit, some samples of duralumin and magnesium alloys were investigated in the usual commercial condition and after being cold drawn to about 13 per cent reduction in cross-section.

All the metals were in the form of round rods. A description of the metals is given in Table I, and details of heat treatment of the steels are given in Table II. For a description of the apparatus and method of test, reference may be made to a preceding paper (7). For a description of the methods of testing at low temperatures, reference may be made to another paper (8).

The 13 per cent chromium, 2 per cent nickel steel was obtained from the Carpenter Steel Co. through the cooperation of G. V. Luerssen. The duralumin was obtained from the Aluminum Company of America through the cooperation of R. L. Templin, Chief Engineer of Tests. The magnesium alloys were furnished by cooperation of the Dow Chemical Co.

The Technical Cohesive Strength and Other Mechanical Properties of 13 per cent Chromium, 2 per cent Nickel Steel and 0.73 per cent Carbon Steel at Room Temperature

Influence of Notch Angle, Notch Depth, and Root Radius on Yield Stress and Ultimate Stress:

In Figs. 1 to 5 are curves showing the variation of the yield stress, ultimate stress, breaking stress, and ductility with the notch angle. Comparison of these curves reveals qualitatively the influence of notch depth and root radius. The diagrams are of two types. Those in Figs. 1, 3, and 4 show the influence of notches on yield stress, ultimate stress, and breaking stress; those in Figs. 2 and 5 show the influence of notches on breaking stress and ductility.[4] Attention will be given first to the curves showing the influence of the notch characteristics on yield stress and ultimate stress (Figs. 1, 3, and 4).

---

[4] Ductility, as in previous papers (7, 8), is expressed in terms of A_0/A, in which A_0 and A represent initial and final areas of cross-section (References 1, 2, 3, and p. 15 of reference 7).

The effect of varying the notch angle, ω, on the yield stress and ultimate stress is the resultant of two variables, the radial stress ratio (S_3/S_1) and the stress concentration. Both the radial stress ratio and the *theoretical* stress concentration increase continuously with decrease in the notch angle. The increasing radial stress ratio tends to cause a continuous rise of a curve of yield stress or ultimate stress. Any stress concentration remaining in the metal decreases the mean stress at yield or at highest load and thus opposes the rise of a curve of yield stress or ultimate stress. Some curves of yield stress or ultimate stress rise continuously under the dominant influence of the continuously increasing radial stress ratio; others eventually descend under the dominant influence of increasing stress concentration.

The 13 per cent chromium, 2 per cent nickel steel was sufficiently ductile to permit the tensile load to reach a maximum with deeply notched specimens (k = 0.18 or less)[5] even when the root radius, r, was only 0.001 in. (Fig. 1). With deeply notched specimens, the influence of stress concentration is minimized and the elevating influence of the increasing radial stress ratio is dominant throughout the entire curve.[5] With shallow notched specimens (k = 0.64 to 0.66) of this metal, the depressing influence of stress concentration eventually predominates and the curve of ultimate stress descends (Fig. 1). Fracture, however, was not "premature," that is, the load reached a true maximum.

The influence of the root radius of the notch is revealed by comparison of the curves obtained with various root radii. For deeply notched specimens of this steel, the height reached by a curve of ultimate stress increases with decrease in the root radius, at least for radii of 0.001 in. or more. The radial stress ratio evidently tends to increase with decrease in the root radius.

The 0.73 per cent carbon steel is not sufficiently ductile to permit the tensile load to reach a maximum when the notch angle and root radius are less than certain values, which depend on the notch depth (Figs. 3 and 4). With root radius 0.01 in., fracture is premature when the notch angle is 120 deg. or less (Fig. 4). With root radius 0.03 or 0.05 in., fracture is premature when the notch angle is 90 deg. or less. With root radius 0.08 in., fracture was not premature. Because the ductility decreases with decrease of the notch angle, the prematurity of fracture increases, and the curves of ultimate stress eventually descend (with the exception of the curve obtained with root radius 0.08 in.).[6] The depressing influence of prematurity of fracture probably is accentuated when the ductility is not sufficient to relieve stress concentration. The mean stress would thus be less than the actual stress at fracture.

With the 0.73 per cent carbon steel, the height reached by a curve of ultimate stress was greatest when the root radius was 0.03 in., was slightly less when the radius was 0.05 in., was considerably less when the radius was 0.01 in., and was much less when the radius was 0.08 in. Although the radial stress ratio tends to be higher with the 0.01 than with the 0.03 in. root radius, the stress concentration also tends to be higher. The radius that gives the highest value of the ultimate stress varies with the ductility of the metal; it is greater for the 0.73 per cent carbon steel than for the more ductile chromium-nickel steel, or for the still more ductile metals considered in previous papers (7, 8).

---

[5] Notch depth is expressed as the ratio k of the reduced area to the section of the specimen before notching. Thus the greater the notch depth, the smaller is the value of k. The influence of notch depth on the theoretical stress concentration and on the ultimate stress is illustrated by Figs. 3, 23, 24, and 25 of a previous paper (7). With increase in the notch depth, the theoretical stress concentration at the root of the notch first increases and then decreases.

[6] The term "ultimate stress" is generally applied to the nominal stress (stress based on the original area of cross-section) when the load reaches a true maximum. The term, however, is here used with broader significance to designate the nominal stress at highest load.

Influence of Notches on the Breaking Stress and Ductility:

Figures 1, 3, and 4 show the variation of the breaking stress with the notch angle, for various values of notch depth and root radius. None of the curves of breaking stress rises continuously with decrease in the notch angle. The variation of the breaking stress with the notch angle is the resultant of three variables dependent on the notch angle. These variables are: the radial stress ratio, stress concentration, and the total deformation at fracture (ductility).[7] With deeply notched specimens of sufficient ductility, the stress concentration at fracture is of minor importance, and the course of a curve of breaking stress depends chiefly on the variations of the radial stress ratio and the ductility with the notch angle. The continuous increase in the radial stress ratio with decrease in the notch angle tends to cause a continuous rise of a curve of breaking stress, but the ductility decreases continuously with decrease in the notch angle (see Figs. 2 and 5), and this variation tends to cause a continuous descent of a curve of breaking stress. With the steels represented in Figs. 1, 3, and 4, the influence of the increasing radial stress ratio predominates in the rises of the curves of breaking stress, and the influence of the decreasing ductility predominates in the descents of these curves. In spite of the great decrease in ductility, every curve obtained with deeply notched specimens of these steels rises above the point representing fracture of an unnotched specimen and well above the still lower point representing approximately the (not directly determinable) stress at fracture under unidirectional tension.

Figures 2 and 5 show the influence of notches on the relation between breaking stress and ductility. The curves of breaking stress in these figures are qualitatively similar to those in the corresponding figures of the previously discussed type, except that the curves of the two types extend in opposite directions from the point (P_0) representing fracture under unidirectional tension. The elevating influence of the increase in radial stress ratio with decrease in the notch angle manifests itself in the general increase of slope of the lines of flow stress drawn between the experimental points representing yield and fracture. The exceptions to this general increase of slope (Fig. 2) must be attributed to the depressing influence of stress concentration. The straight lines representing flow stress do not represent flow under constant radial stress ratio; the radial stress ratio generally increases with the changes in the notched specimen during plastic deformation. If the radial stress ratio could be kept constant, the lines of flow stress would be curved (7). The significance of the lines representing flow stress of an unnotched specimen is discussed on page 15 of a previous paper (7).

If it were possible to make tests with the radial stress ratio held constant, and without stress concentration, and if it were possible to obtain a quantitatively correct measure of the ductility (page 18 of reference 7), the course of a curve of breaking stress would depend only on the variable radial stress ratio, and the relation between breaking stress and ductility would be represented by a single curve. Such a curve may be represented qualitatively by the ideal locus of fractures, curve *L*.

---

[7] As shown in previous papers (4 to 8), plastic extension causes a continuous increase in the technical cohesive strength and hence tends to cause increase in any specific technical cohesion limit.

The ductility expressed in terms of the change in cross-sectional area can be determined with sufficient accuracy. The value so obtained, however, is merely a mean value. The true ductility, represented by the plastic deformation at the origin of fracture, generally differs from the mean ductility because of the deformation gradient that arises during plastic deformation of a notched specimen. When fracture starts near the axis of the specimen, as it generally does when fracture is not premature, the mean ductility is generally greater than the true ductility. This difference is accentuated when there is a "rim" effect, that is, a continued plastic deformation of the rim of the minimum cross-section after fracture has started near the center (7). To study this rim effect, longitudinal sections have been made through fractured specimens having various initial notch angles and root radii. This study has shown that the rim effect, in specimens of the steels represented in Figs. 2 and 5, is prominent, when the root radius is 0.05 or 0.08 in., but is negligible for root radii of 0.03 in. or less. The effect increases the apparent breaking stress and the mean ductility above their correct values. For this reason, the ideal locus of fractures in Figs. 2 and 5 has been drawn with little regard for the curves representing root radii greater than 0.03 in.

The Disruptive Stress:

Each ideal locus of fractures must reach the axis of abscissas at a point, T_1, whose ordinate represents the disruptive stress.[8] This stress cannot be determined directly and can be estimated only approximately. For the 13 per cent chromium, 2 per cent nickel steel, the disruptive stress has been represented by a point, T_1, slightly above point *E* in Fig. 1. Point *E* represents by its ordinate the (imaginary) ultimate stress corresponding to zero values of both ω and *k*, for root radius 0.001 in.; it is obtained by extrapolation to zero value of *k*, making use of the uppermost curve of ultimate stress (Fig. 1). Point T_1, as indicated, probably should be not far above *E* and below the summit of the highest curve of breaking stress in Fig. 1.

For the 0.73 per cent carbon steel, because of the tendency to premature fracture, much longer extrapolation must be used to represent the course of a curve of true ultimate stress (nominal stress when the tensile load reaches a true maximum). Such extrapolation has been used in obtaining curves *U′* in Figs. 3 and 4. As the available evidence suggests that the disruptive stress generally is not far from twice the ultimate stress of an unnotched specimen, values obtained on this assumption have been used in locating points T_1 in Figs. 3, 4, and 5.

The Technical Cohesive Strength, Yield Strength, and Ultimate Strength in terms of Combined Axial and Radial Stresses:

When S_2 is kept equal to S_3 the strength of a metal may be represented by a diagram with ordinates representing axial stresses and abscissas representing radial stresses. Diagrams of this type for the chromium-nickel steel have been given in previous papers (7, 8). Diagrams of the same type for the 0.73 per cent carbon steel are given in Fig. 6. These diagrams are assumed to be free from the distorting influence of stress concentration; they are presented as qualitative representations of the strength of this steel in terms of *uniform* axial and radial stresses. The values of S_3 and of S_3/S_1 used in constructing these diagrams cannot be obtained directly from the results of tests of notched specimens, but must be based on an empirical assumption as to the variation of S_3/S_1 with the notch angle (7, 8).

---

[8] The term "disruptive stress" has been suggested to indicate the stress at fracture under polarsymmetric tension (4). As this stress combination causes no shear, there can be no plastic deformation.

Each of the radiating broken lines in Fig. 6 is the locus of points representing the indicated constant value of the radial stress ratio; the diagonal line H is the locus of points representing polarsymmetric stress ($S_1 = S_2 = S_3$).

Point T_1 in each diagram is the junction of the locus of fractures and the curves of yield strength, ultimate strength, and initial technical cohesive strength. Curve T represents approximately the *initial* technical cohesive *strength*, and the intersections of curve T with the radiating broken lines represent initial cohesion *limits* for the corresponding values of S_3/S_1. The initial technical cohesion limit for any specific value of S_3/S_1 cannot be represented by a point on curve L, because fracture of a ductile metal occurs only after the technical cohesive strength has been increased by plastic deformation. The initial technical cohesive *strength* should be represented by a curve, T, between the curve of yield strength and the locus of fractures (7, 8, 10).

The Influence of Plastic Deformation on Technical Cohesive Strength:

In diagrams of the type now to be discussed, abscissas represent plastic deformation and ordinates represent breaking stresses; the system of coordinates, therefore, is the same as in the diagrams shown in Figs. 2 and 5. Diagrams of this type are shown in Fig. 7. The locus of fractures, L, in each diagram is practically identical with the ideal locus of fractures in the corresponding diagram of Fig. 2 or Fig. 5. Each locus of fractures, therefore, is assumed to be free from the distorting influence of stress concentration and deformation gradient; it, therefore, is a qualitative representation of the influence of combined axial and radial uniform stresses on the relation between breaking stress and ductility. It is also assumed that any point on the locus of fractures represents fracture in a test with the radial stress ratio held constant.

Any point on the locus of fractures may be made the terminus of a curve of flow stress and of a curve of technical cohesive stress for a specific value of the radial stress ratio. In Fig. 7 two such pairs of curves have been drawn to represent the variation of flow stress and cohesion limit when S_3/S_1 is zero. Curves of cohesion have also been drawn to represent typical values of S_3/S_1 between 0 and 1, but the corresponding curves of flow stress have been omitted.

THE TECHNICAL COHESIVE STRENGTH AND OTHER MECHANICAL PROPERTIES OF DURALUMIN AT ROOM TEMPERATURE, AT −78C., AND AT −188 C.

For a satisfactory study of the technical cohesive strength of a metal, consideration must be given to the influence of *prior* plastic deformation. In this study of the technical cohesive strength of duralumin, therefore, experiments have been made not only with metal as received (heat treated) from the manufacturers, but also with the same metal after cold drawing to about 13 per cent reduction in cross-section. The metal in each state was tested at room temperature, at the temperature of solid carbon dioxide (−78 C.), and at the temperature of liquid air (−188 C.).

Influence of Notch Characteristics on Yield Stress and Ultimate Stress of Duralumin:

In Figs. 8 and 9 are curves showing the variation of the yield stress, ultimate stress, and breaking stress with the notch angle. Attention will be given first to the curves of variation of yield stress and ultimate stress. In Fig. 8 a comparison is made between the diagrams obtained with the "as received" duralumin (DA) and the cold-drawn duralumin (DAH) at room temperature. With the metal in either condition, premature fractures were obtained when the notch angle was less than a certain value. With the "as received" metal, fracture was premature when the angle was 120 deg. or less; with the cold-drawn metal, fracture was premature when the angle was 90 deg. or less.[9] In Fig. 9, comparison of diagrams *A* and *B* with diagrams *C* and *D* shows the influence of cold work, and comparison of diagrams *A* and *C* with diagrams *B* and *D* shows the influence of temperature. The tendency to premature fracture evidently increases with decrease in temperature. The tendency is slightly increased when the temperature is lowered from room temperature to −78 C., but is greatly increased when the temperature is lowered to −188 C. With the cold-drawn metal at −188 C., fracture was premature when the notch angle was 150 deg. or less. Curves *U'* have been drawn by extrapolation to indicate the course of curves of true ultimate stress.

The curves of ultimate stress (Figs. 8 and 9) reach the greatest height when the root radius is 0.03 in.; the height attained is a little less when the radius is 0.05 in. and is considerably less when the radius is either 0.08 or 0.01 in. The greatest value of yield stress at room temperature was reached with root radius 0.01 in. (Fig. 8).

Influence of Notches on Breaking Stress and Ductility of Duralumin:

The height attained by a curve of breaking stress increases with increase in the root radius, at least within the range 0.01 to 0.08 in. (diagrams *B* and *D* of Fig. 8). As shown in diagrams *A* and *D* of Fig. 10, this increase in the breaking stress is due to an increase in the ductility; with increase in the root radius the curve of breaking stress is moved outward and upward. (The slope of a flow-stress line for a given notch angle, however, changes little with increase in the root radius). If this effect of increase of the root radius were due entirely to decrease in stress concentration, the outermost curve (Fig. 10(*a*) or 10(*d*)) would be selected as the best representation of the influence of the radial stress ratio on the relation between breaking stress and ducility. Examination of longitudinal sections after fracture, however, shows that the "rim effect" is prominent in specimens with root radius 0.05 or 0.08 in. Consequently, the values of mean stress and ductility represented by the corresponding curves in Fig. 10 are too high. As practically no rim effect was obtained with root radius either 0.01 or 0.03 in., the curve representing 0.03 in. radius was used as a basis for the ideal locus of fractures, *L*.

Comparison of the diagrams for cold-drawn duralumin (diagrams *D*, *E*, and *F* of Fig. 10) with the corresponding diagram for "as received" duralumin (diagrams *A*, *B*, and *C*) shows that the prior plastic deformation has had little effect on the breaking stress of the unnotched specimens, though it has caused the expected decrease in ductility. The prior plastic deformation, however, has elevated the curves of breaking stress at and near the left ends, thus eliminating the nearly horizontal portion obtained with the "as received" metal. Decrease of temperature has elevated both the curve F of flow stress of an unnotched specimen and the entire curve of breaking stresses but the change of form of the curve of breaking stresses is less prominent than the change caused by prior plastic deformation. These effects of temperature are slight when the change is from room temperature to −78 C., but are much greater when the change is from −78 C. to −188 C.

---

[9] Prior cold work generally decreases the tendency to premature fracture of a notched specimen because the cold work decreases the amount of plastic deformation that the specimen must undergo before reaching maximum load. Moreover, because the rate of work hardening has been decreased by the prior cold work, relief of stress concentration is facilitated, and thus the tendency to premature fracture is decreased.

Prior plastic deformation increases the vertical (stress) range of an experimentally determined curve of breaking stresses and decreases the horizontal range (ductility). Prior plastic deformation thus makes more prominent the influence of one of the variables (radial stress ratio) involved in the curve of breaking stress, and makes less prominent the influence of the other variable (ductility). This effect of prior plastic deformation is greatly accentuated when the temperature is lowered to −188 C. (compare Fig. 10 (*d*) and (*f*)).

As illustrated by the relative positions of curves F and F_0 in Fig. 10, the local contraction of an unnotched specimen of this material evidently is not sufficient to induce much radial stress, even in a specimen of the "as received" metal at room temperature. The stress at fracture, consequently, differs little from the technical cohesion limit for unidirectional tension, and the difference decreases with prior cold work and with temperature. At −188C., the stress at fracture is practically unidirectional (diagrams C and F). As shown in Fig. 10 (*f*), therefore, the highest breaking stress obtained with a notched specimen at −188 C. was nearly 50 per cent greater than the technical cohesion limit for unidirectional tension, although the radial stress ratio for this notched specimen probably was much less than 1.0. If polarsymmetric tension could be applied, the breaking stress (disruptive stress) probably would be about twice the technical cohesion limit for unidirectional tension.

The Technical Cohesive Strength, Yield Strength, and Ultimate Strength of Duralumin in terms of Combined Axial and Radial Stresses:

Figure 11 contains diagrams showing qualitatively the technical cohesive strength, yield strength, and ultimate strength of duralumin at room temperature, at −78 C., and at −188 C. The diagrams are of the same type as the previously described diagrams for steels in Fig. 6. They are qualitative representations of the strength of the metal in terms of *uniform* axial and radial stresses. Each subdivision of Fig. 11 contains a diagram representing the strength of the metal in the "as received" condition and a diagram representing the strength of the same metal after considerable prior plastic deformation (about 13 per cent reduction in cross-section). Figure 11 (*a*) also contains a curve representing approximately the strength of duralumin that has been cold worked to the limit, as by rolling or by some other stress combination not involving tension.

In each diagram for "as received" duralumin (solid curves), the curves representing yield strength, ultimate strength, and breaking strength are far apart throughout the field representing negative values of S_3, and throughout much of the field representing positive values of S_3. In each diagram for cold-worked metals (broken curves), however, the curve of ultimate stress is much nearer to the locus of fractures, and a curve of yield stress (not shown) would be only slightly below the curve of ultimate stress. To avoid confusion, the curves representing *initial* technical cohesive strength have not been included. These, as in Fig. 6, would almost coincide with the corresponding curves of ultimate strength. The greater the amount of prior plastic deformation, the nearer together are the curves representing yield strength, ultimate strength, and locus of fractures. For a metal that has been plastically deformed to the limit, under a stress combination not involving tension, the three curves would coincide, as illustrated by the curve designated T'' and L'' in Fig. 11 (*a*). The technical cohesive strength of a brittle metal is represented by a curve of this form (4, 5, 10).

Within the field of negative values of S_3, the locus of fractures, L, is practically unaffected by *prior* plastic deformation. Under any specific stress combination within this field, the breaking stress would be expected to be practically the same whether the plastic deformation has occurred before or during experiments on which the diagram is based. Prior plastic deformation in the field of negative values of S_3, however, elevates the locus of fractures within the field of positive values of S_3, and moves the point T_1 representing the disruptive stress upward along line II.

The Influence of Plastic Deformation on the Technical Cohesive Strength of Duralumin:

In the diagrams that have just been discussed (Fig. 11) the influence of plastic deformation manifests itself in its effect on the indices of strength, but plastic deformation is not represented directly. In diagrams of the type now to be considered (Fig. 12) abscissas represent plastic deformations and ordinates represent breaking stresses. The system of coordinates is the same as in the diagrams of Figs. 7 and 10. The locus of fractures in each diagram of Fig. 12 is identical with the "ideal" locus of fractures in the corresponding diagram of Fig. 10, but the order of arrangement of the diagrams in Fig. 12 differs from the order in Fig. 10. The diagrams in Fig. 12 are arranged in three pairs each representing the technical cohesive strength at the indicated temperature.

The variation of the disruptive stress with plastic deformation is represented by curve T_1 in each diagram. A curve of variation of a single *technical cohesion limit*, however, is not an adequate representation of the influence of plastic deformation on the *technical cohesive strength*. A complete representation would comprise a series of curves, each corresponding to a typical value of S_3/S_1; each curve of a series should be qualitatively similar to curve T_1. Such a series of curves has been placed in each diagram of Fig. 12. The corresponding curves of flow stress have been omitted except the curve of unidirectional flow stress (F_0). A curve of flow stress rises more rapidly than the corresponding curve of cohesion. Although the two curves may be far apart at the origin, they converge and eventually intersect at a small angle, at a point on the locus of fractures.

The effect of *prior* plastic deformation on the technical cohesive strength may be studied by comparing the diagrams representing "as received" metal (diagrams *a*, *c*, and *e* of Fig. 12) with the corresponding diagrams representing cold-worked metal (diagrams *b*, *d*, and *f*). The evidence indicates that prior plastic deformation has very little effect on the stress at fracture under unidirectional tension, because this point represents fracture after about the same total plastic extension whether or not the metal has been plastically deformed before test. Prior plastic deformation, however, elevates the locus of fractures at and near the left end.

When the degree of plastic deformation is represented as in Fig. 12, a curve of technical cohesion for a previously cold-worked metal should be approximately an extension of the corresponding curve beyond the proper abscissa in a diagram for "as received" metal. Use has been made of this principle in constructing the curves of cohesion in diagrams *b*, *d*, and *f* of Fig. 12.

Because the rate of work-hardening increases with decrease in the temperature, the curves of cohesion in Fig. 12 are steepest in diagrams *e* and *f*, and are slightly steeper in diagrams *c* and *d* than in diagrams *a* and *b*. This relationship is qualitatively similar to the relationship between the slopes of the curves of flow stress in Fig. 10.

THE TECHNICAL COHESIVE STRENGTH AND OTHER MECHANICAL PROPERTIES OF MAGNESIUM ALLOYS

For a study of the technical cohesive strength of magnesium alloys, experiments have been made with notched specimens of an alloy (MJ) as received and of the same alloy after cold drawing to about 13 per cent decrease in area of cross section (MJH). At −78 C. and −188 C., the ductility of the magnesium alloys was decreased so much that satisfactory diagrams of technical cohesive strength could not be obtained. At −78 C., fracture was premature when the notch angle was 120 deg. or less (Fig. 13); at −188 C., the breaking stresses were lower for specimens with notch angles 120 and 90 deg. than for an unnotched specimen (Fig. 13 *d*). Study of the technical cohesive strength, therefore, has been confined chiefly to experiments at room temperature. The results of these experiments are given in diagrams *a* and *b* of Fig. 13 and in Fig. 14.

For the alloy as received (MJ), the highest curve of ultimate stress was obtained with root radius 0.05 in. (Fig. 13 *a*). The radius that gave best results, therefore, was larger for this alloy than for steels or duralumin. Although the alloy at room temperature showed little tendency to premature fracture, evidence now to be considered indicates that important stress concentration was present at maximum load and at fracture. Notches caused great decrease in ductility, even when the notch angle was as large as 170 deg. (Fig. 14 (*a*)), yet the experimental points obtained with notch angles 150 to 170 deg. are only slightly above the line, *F*, of flow stress for an unnotched specimen. As the lines of flow stress obtained with the notched specimens (the sloping broken lines in Fig. 14 (*a*) are much less steep than line *F*, the mean stresses at fracture probably were considerably less than the true stresses at the origin of fracture. The experimental points for notched specimens in this diagram, therefore, probably are too low because of stress concentration. On the basis of the evidence in Fig. 14 (*a*), consequently, it is not possible to construct a curve to represent the locus of fractures.

With the cold-drawn alloy MJH, it was possible to reveal qualitatively the relation between breaking stress and ductility (Fig. 14 (*b*)). Although notches cause great decrease in ductility, the slope of the flow-stress line increases with decrease in the notch angle, thus indicating that the increase in the radial stress ratio due to the notch has had an appreciable effect on the mean stress at fracture. The results obtained reveal clearly the form of the locus of fractures, and show that the locus for this alloy is similar in form to the locus of fractures for duralumin. The point T_1 in Fig. 14 (*b*) has been located on the assumption that the disruptive stress is about twice the ultimate stress for an unnotched specimen, and a curve L has been drawn to represent qualitatively the ideal locus of fractures. A similar curve has been drawn in Fig. 14 (*a*) to represent the ideal locus of fractures for the "as received" alloy.

Diagrams to represent the technical cohesive strength in terms of combined axial and radial stresses, and diagrams to represent the influence of plastic deformation on the technical cohesive strength, evidently would be similar in form to the diagrams for duralumin (Figs. 11 and 12). If uniform axial and radial stresses could be applied experimentally, diagrams could be obtained to represent the technical cohesive strength of magnesium alloys at low temperatures.

THE VARIATION OF THE STRENGTH AND DUCTILITY OF DURALUMIN AND MAGNESIUM WITH TEMPERATURE

The previously discussed diagrams for duralumin and magnesium show qualitatively the influence of temperature on the strength of these alloys. To study the quantitative variation of strength with temperature, supplementary experiments have been made with unnotched specimens at additional temperatures ranging between −100 C. and −188 C. Results of these experiments, together with the previously discussed results obtained at room temperature, −78 C., and −188 C., are given in Fig. 15, 16, and 17. Magnesium alloy MK (Fig. 16) is of the same composition as alloy MJH; results obtained with these alloys, therefore, may be compared with the results shown in Figs. 13 and 14. Results of experiments with two additional magnesium alloys are shown in Fig. 17.

The temperature scale used in Figs. 15 to 18 is the same that has been used in a previous paper (8). In that paper, it was shown that the strength of copper, monel metal, and some steels varies linearly with the logarithm of the temperature expressed in deg. K, a scale the same in principle as Kelvin's original thermodynamic scale. With nickel and high-purity aluminum, the linear relationship extended only from −188 C. to −78 C.; above −78 C., there was evidence of some strengthening factor, which is thought to be due to structural changes such as strain aging. As shown in Figs. 15 to 17, however, a linear relationship was not obtained with duralumin and the magnesium alloys, even between −188 C. and −78 C. It seems probable that the departures from the linear relationship are due to some structural changes, which vary with the temperature.

The curves representing the strength of notched specimens of duralumin (Fig. 15) evidently are similar in form to the curves for unnotched specimens. Comparison should be made between the relative positions of the curves representing strength of notched specimens and the curve of breaking stresses of unnotched specimens. For the "as received" duralumin (Fig. 15 *a*), the curve of breaking stresses obtained with notch angle 150 deg. is slightly above the curve of breaking stresses of unnotched specimens, and the curve of breaking stresses obtained with notch angles 60 and 40 deg. is considerably higher. Even the curve of ultimate stresses for notch angles 60 and 40 deg. is considerably above the curve of breaking stresses of unnotched specimens. For the cold-drawn duralumin (Fig. 15 *b*), the curves for ultimate stresses and breaking stresses of specimens with notch angles 150 deg. or less are above the curve of breaking stresses of unnotched specimens. Even curves of yield stress (not shown) of specimens with small notch angles would be far above the curve of breaking stresses of unnotched specimens.

The curve of disruptive stresses (T_1) is drawn in accordance with the approximately established positions of points T_1 in Fig. 10. A curve of variation of a single technical cohesion limit, however, does not adequately represent the variation of the technical cohesive strength. Adequate representation would comprise a series of curves, representing the initial technical cohesion limits for typical radial stress ratios. In Fig. 15 (*b*), only two such curves are drawn, curves T_1 and T_0.

Figure 18 shows the influence of temperature on the ductility of the previously discussed duralumin and magnesium alloys. The effect of temperature on the ductility of these alloys is most prominent with unnotched specimens. The effect of notches on ductility is greatest at room temperature. With decrease of temperature, the ductility of even unnotched specimens is so much reduced that notches have little additional effect.

REFERENCES

(1) C. W. MacGregor, "Relation between Stress and Reduction of Area for Tensile Test of Metals", *Transactions*, Am. Inst. Mining and Metallurgical Engrs., Vol. 124, pp. 208–226 (1937).

(2) C. W. MacGregor, "A Two-Load Method for Determining the Average True Stress-Strain Curve in Tension", *Transactions*, Am. Soc. Mechanical Engrs., Vol. 61, pp. 156–158 (1939).

(3) C. W. MacGregor, "The Tension Test", *Proceedings*, Am. Soc. Testing Mats., Vol. 40, p. 508 (1940).

(4) D. J. McAdam, Jr., "The Technical Cohesive Strength of Metals", *Transactions* Am. Soc. Mechanical Engrs., Vol. 63, *Journal of Applied Mechanics*, Vol. 8, December 1941, pp. A 155–165 (1941).

(5) D. J. McAdam, Jr., "The Technical Cohesive Strength and Yield Strength of Metals", Am. Inst. Mining and Metallurgical Engrs., *Technical Publication No. 1414*, 47 pp., January, 1942; also *Transactions*, Vol. 150 (Iron and Steel Division), pp. 311–357 (1942).

(6) D. J. McAdam, Jr., "The Influence of the Combination of Principal Stresses on Fatigue of Metals," *Proceedings*, Am. Soc. Testing Mats., Vol. 42, p. 576 (1942).

(7) D. J. McAdam, Jr., and R. W. Mebs, "An Investigation of the Technical Cohesive Strength of Metals", Am. Inst. Mining and Metallurgical Engineers, *Technical Publication No. 1615*, 63 pp., *Metals Technology*, Vol. 10, August, 1943.

(8) D. J. McAdam, Jr., and R. W. Mebs, "The Technical Cohesive Strength and Other Mechanical Properties of Metals at Low Temperatures," *Proceedings*, Am. Soc. Testing Mats., Vol. 43, p. 661 (1943).

(9) D. J. McAdam, Jr., and G. W. Geil, "The Variation of the Strength, Resistence to Oxidation, and Electrical Conductivity of Metals with Temperature," *Transactions*, Am. Soc. Metals, Vol. 33, pp. 514–534 (1944).

(10) D. J. McAdam, Jr., "The Technical Cohesive Strength of Metals in Terms of the Principal Stresses," Paper presented at Am. Inst. Mining and Metallurgical Engineers, Symposium on Cohesion, October 19, 1943.

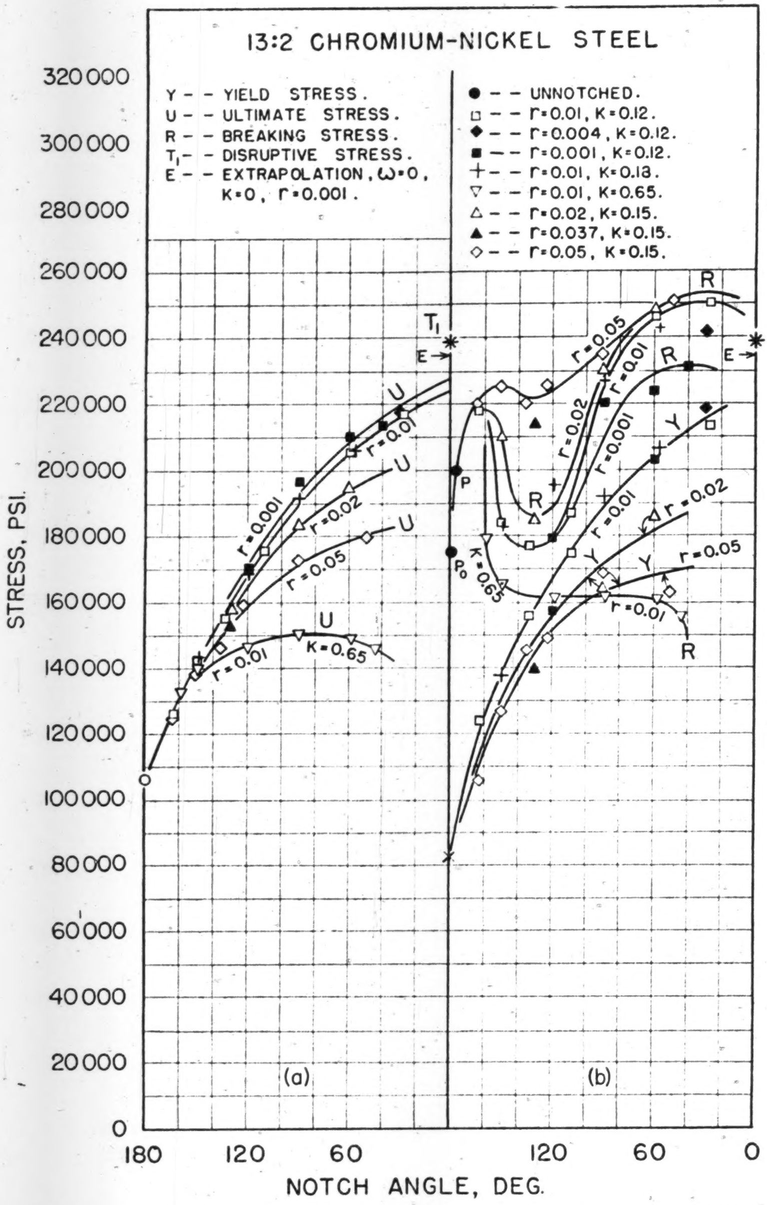


Fig. 1.—Influence of Notches on Yield Stress, Ultimate Stress, and Breaking Stress of 13:2 Chromium-Nickel Steel at Room Temperature.

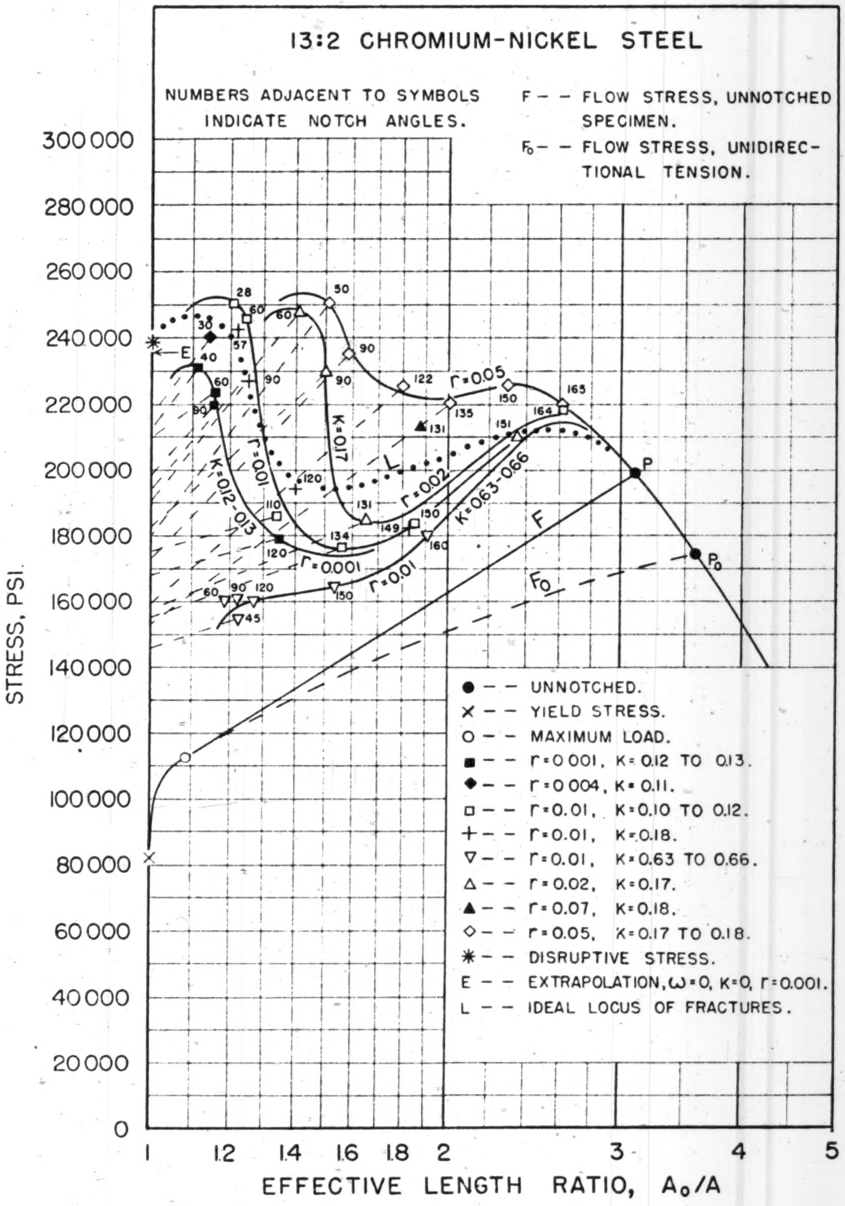


Fig. 2.—Influence of Notches on Breaking Stress and Ductility of 13:2 Chronium-Nickel Steel at Room Temperature.

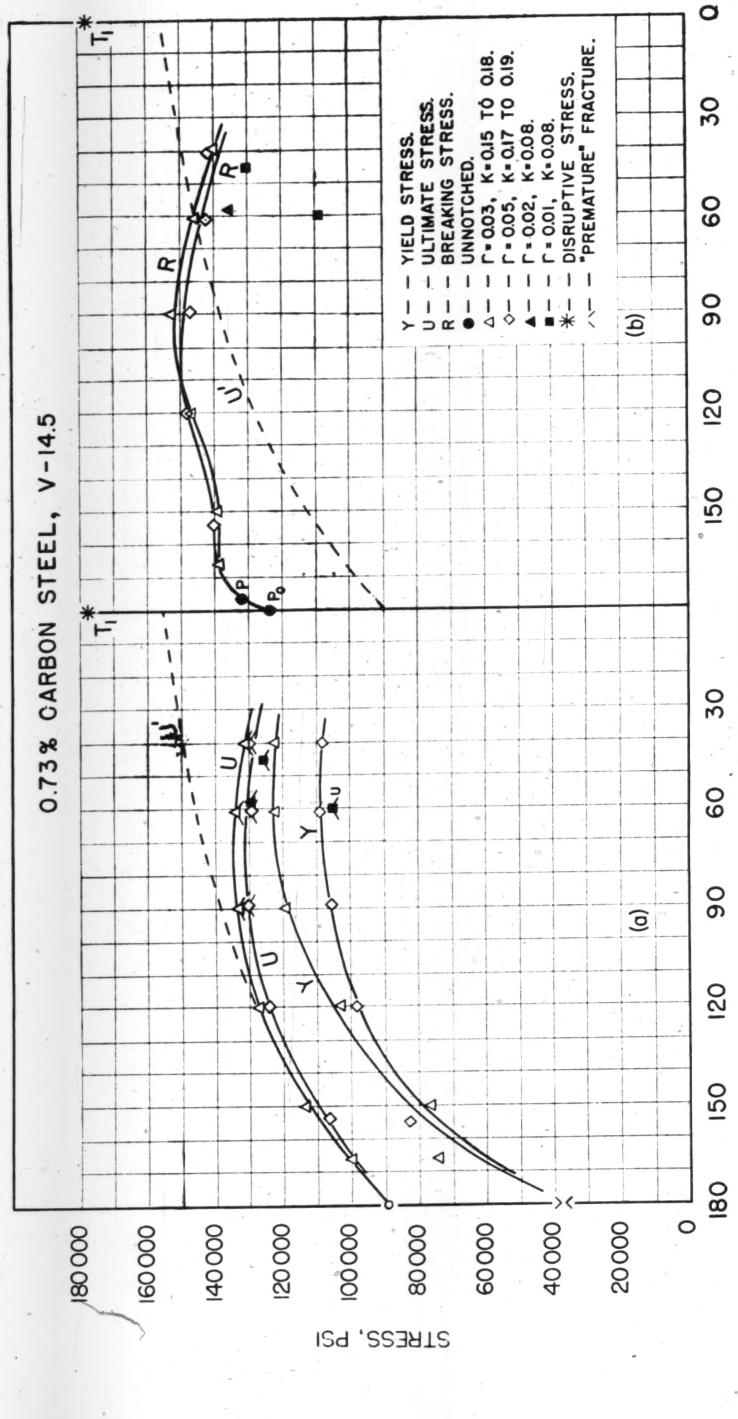


FIG. 3.—Influence of Notches on Yield Stress, Ultimate Stress, and Breaking Stress of Annealed 0.73 Per Cent Carbon Steel at Room Temperature.

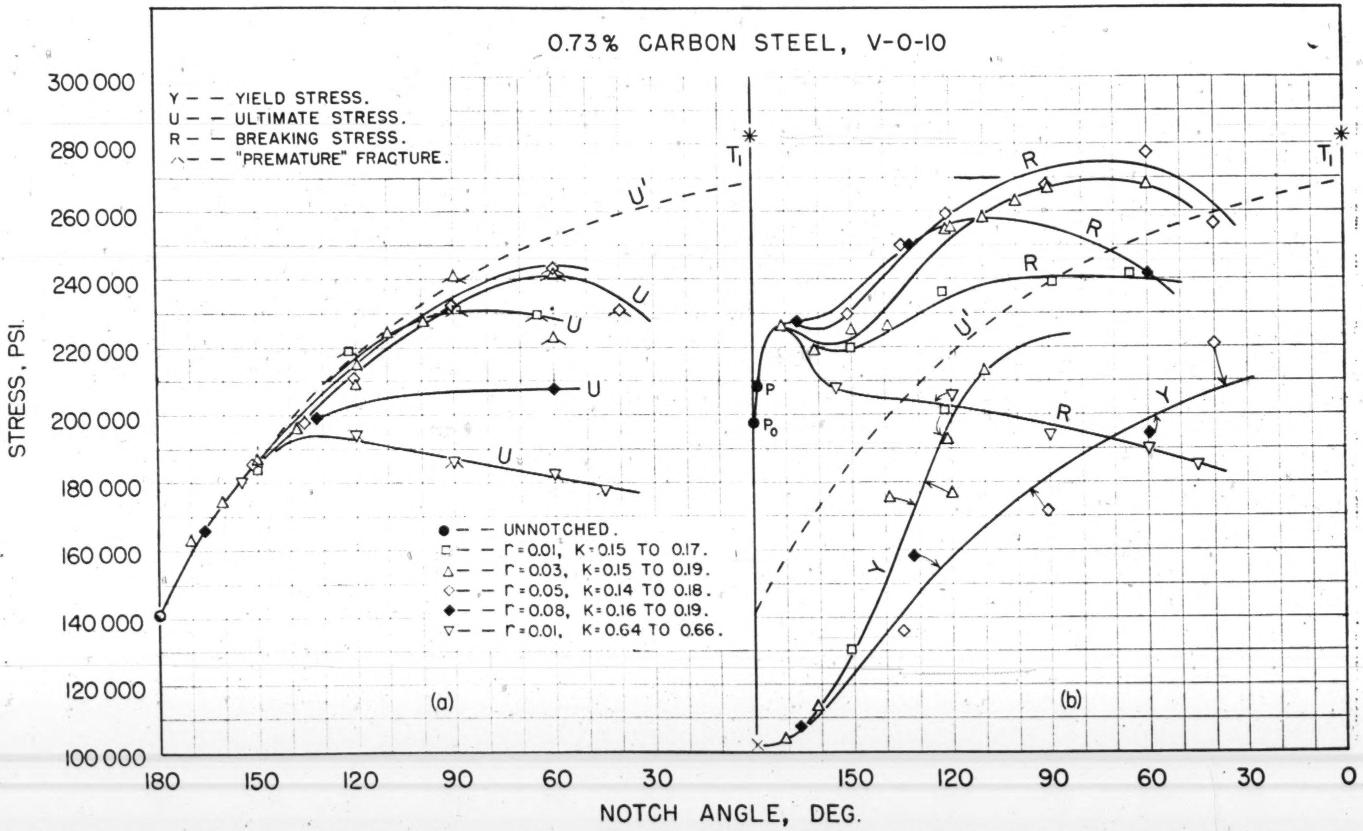


FIG. 4.—Influence of Notches on Yield Stress, Ultimate Stress, and Breaking Stress of Heat Treated 0.73 Per Cent Carbon Steel at Room Temperature.

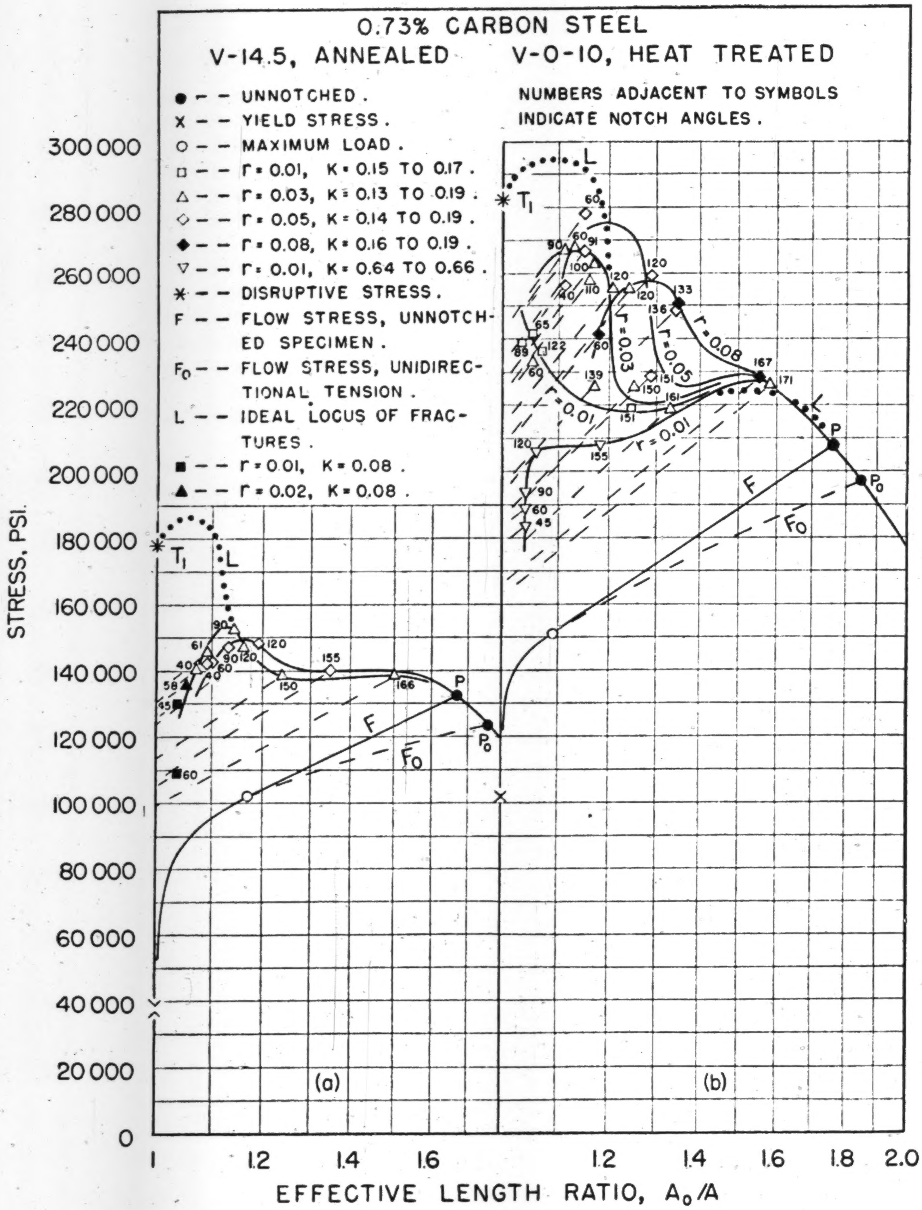


FIG. 5.—Influence of Notches on Breaking Stress and Ductility of 0.73 Per Cent Carbon Steel at Room Temperature.

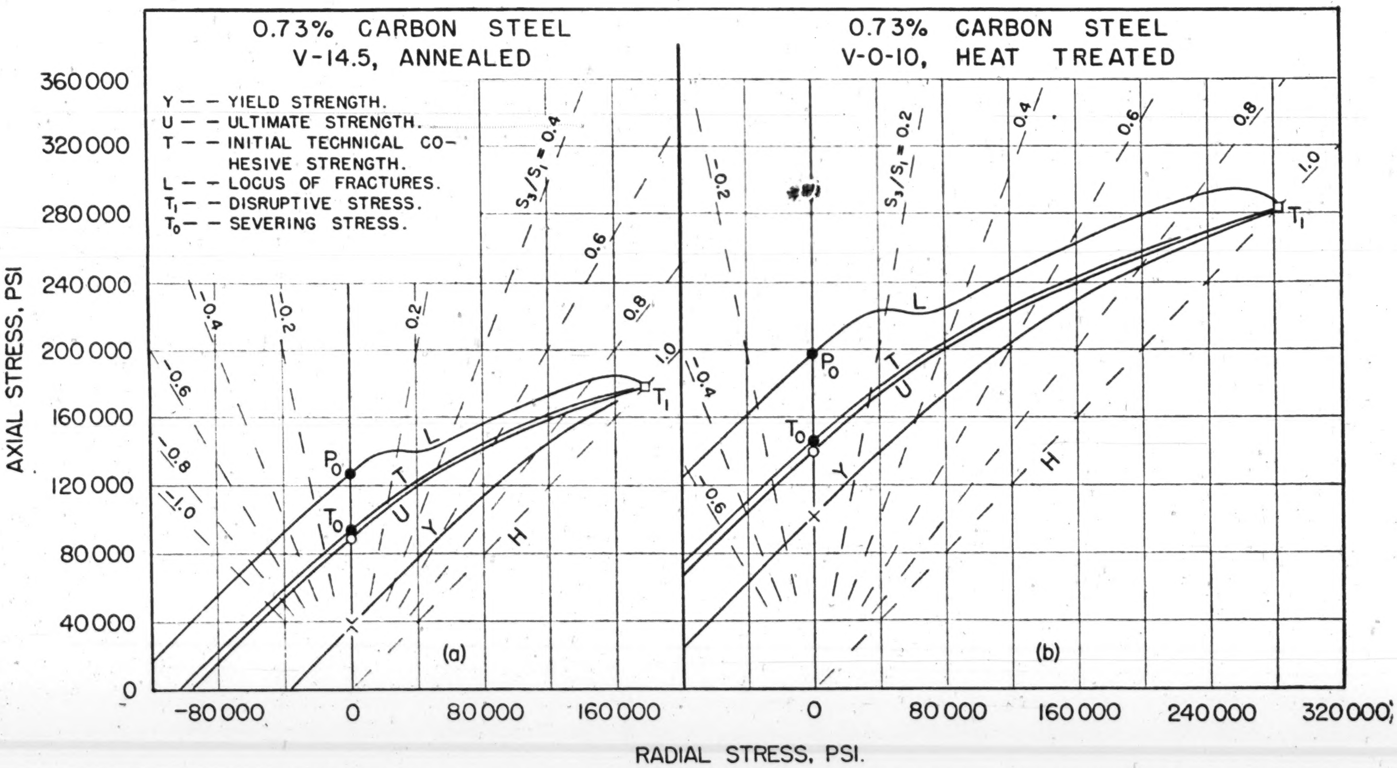


FIG. 6.—Influence of the Radial Stress Ratio on Yield Stress, Ultimate Stress, and Technical Cohesion Limit of 0.73 Per Cent Carbon Steel at Room Temperature.

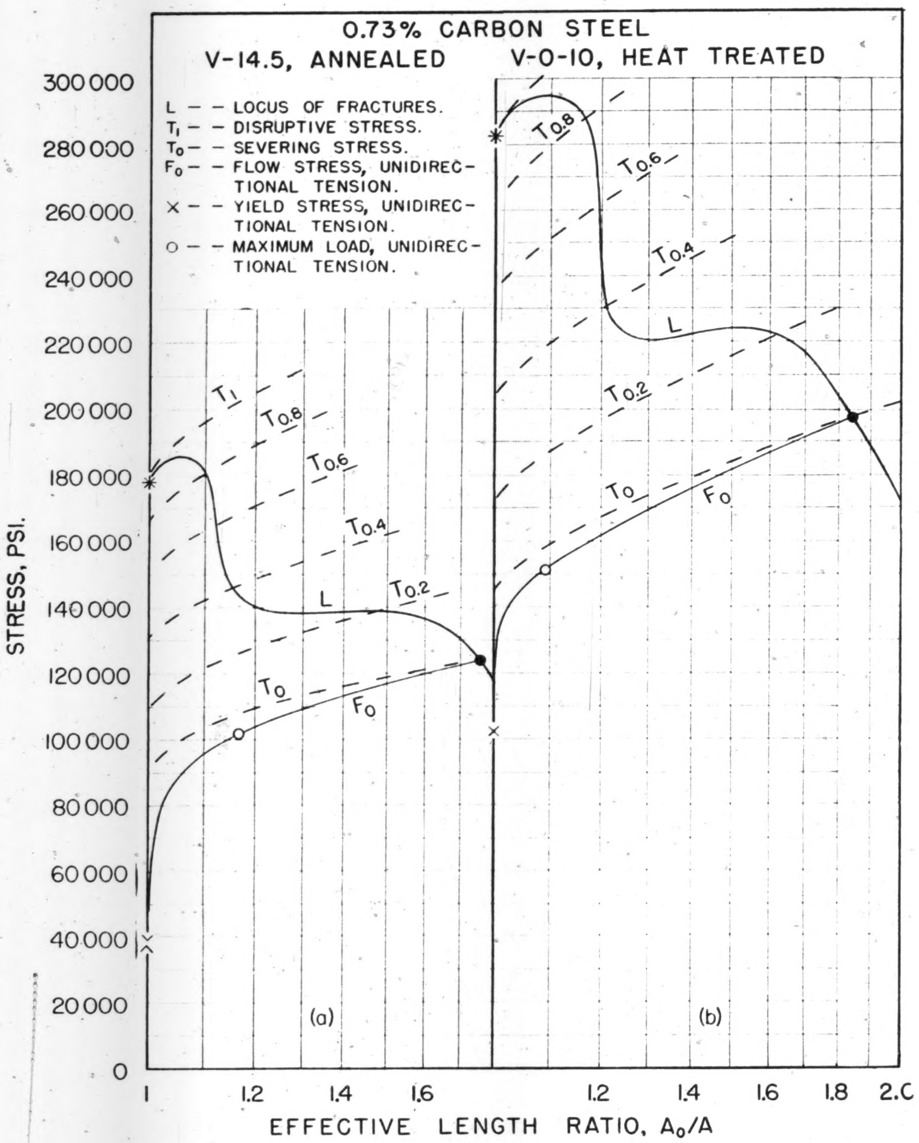


FIG. 7.—Influence of Plastic Deformation on Technical Cohesive Strength of 0.73 Per Cent Carbon Steel at Room Temperature.

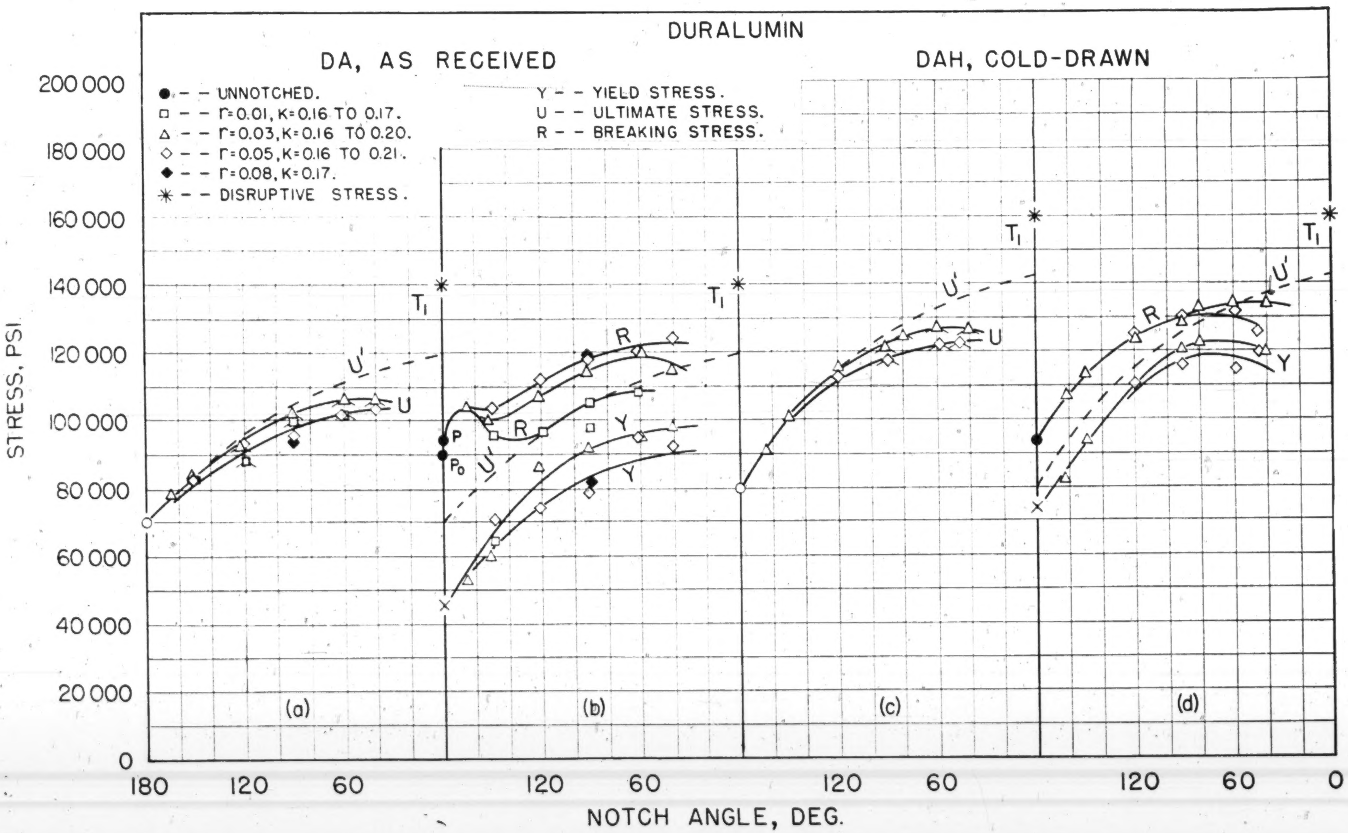


FIG. 8.—Influence of Notches on Yield Stress, Ultimate Stress, and Breaking Stress of Duralumin at Room Temperature.

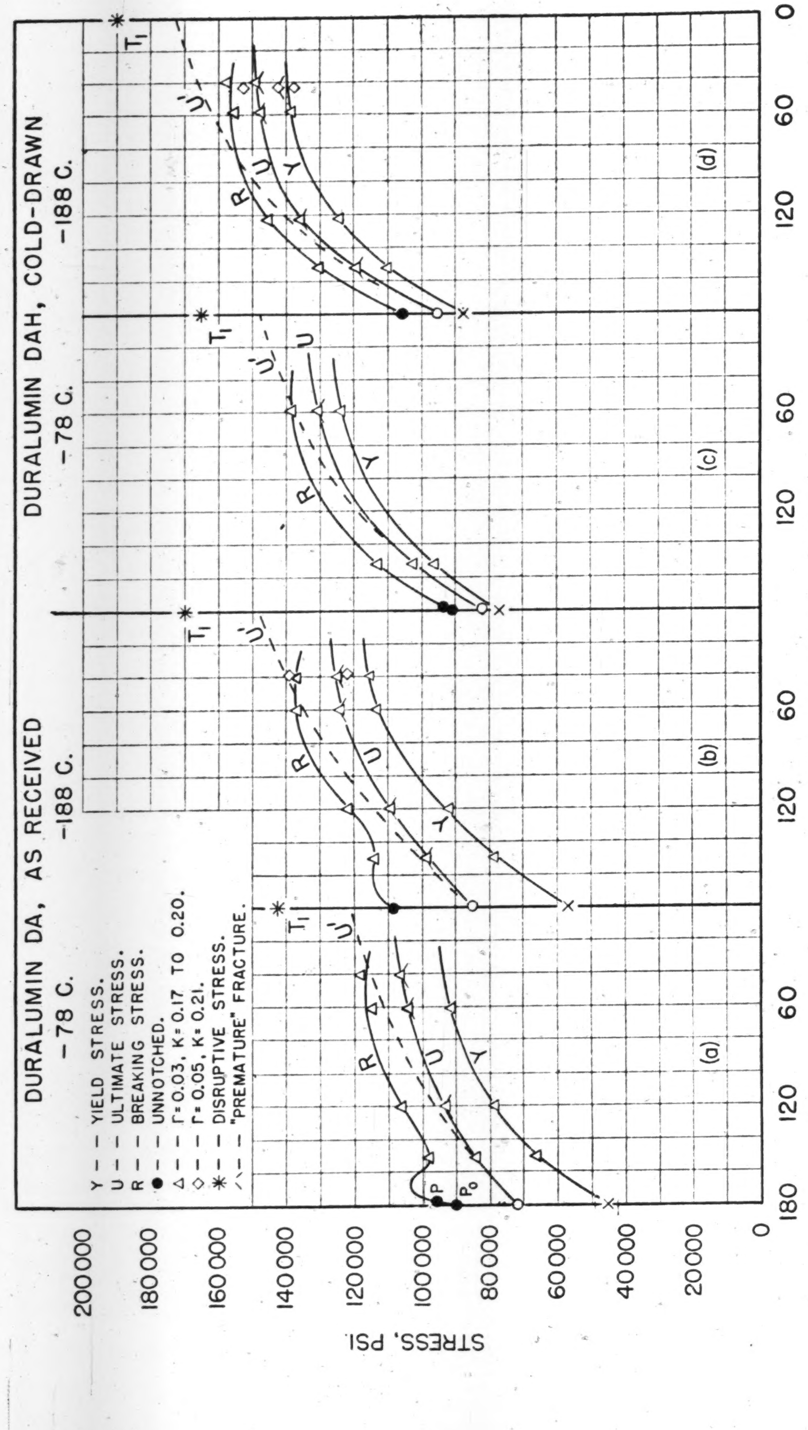


Fig. 9.—Influence of Notches on Yield Stress, Ultimate Stress, and Breaking Stress of Duralumin at Two Different Temperatures.

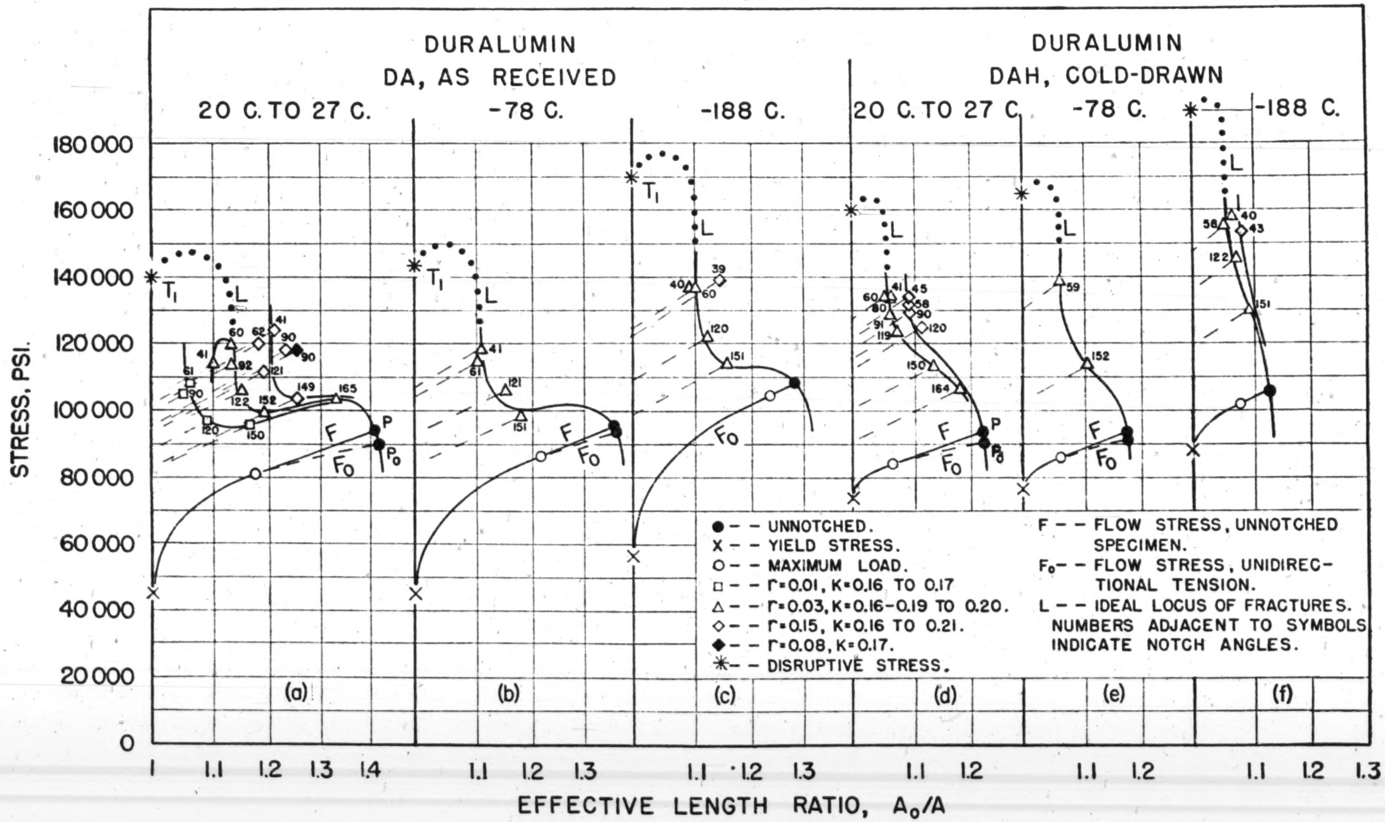


Fig. 10.—Influence of Notches on Breaking Stress and Ductility of Duralumin at Three Different Temperatures.

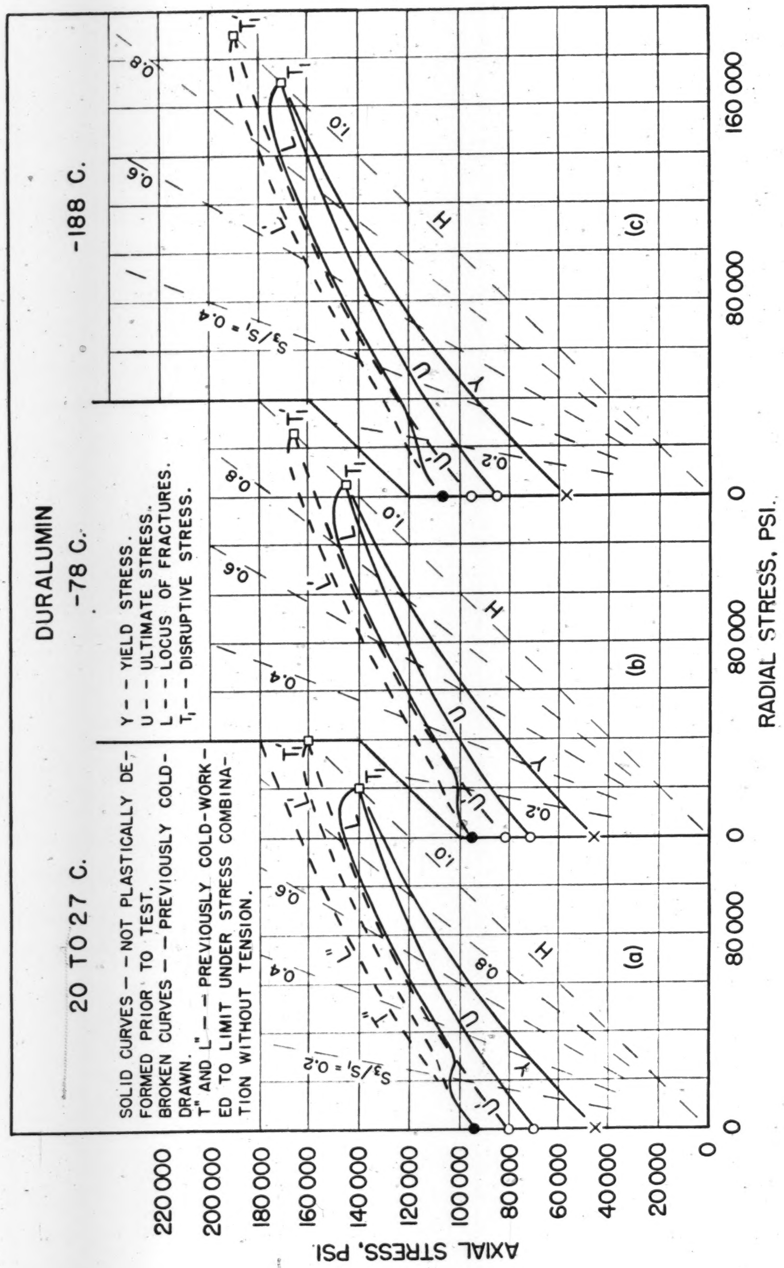


Fig. 11.—Influence of the Radial Stress Ratio on Yield Stress, Ultimate Stress, and Technical Cohesion Limit of Duralumin at Three Different Temperatures.

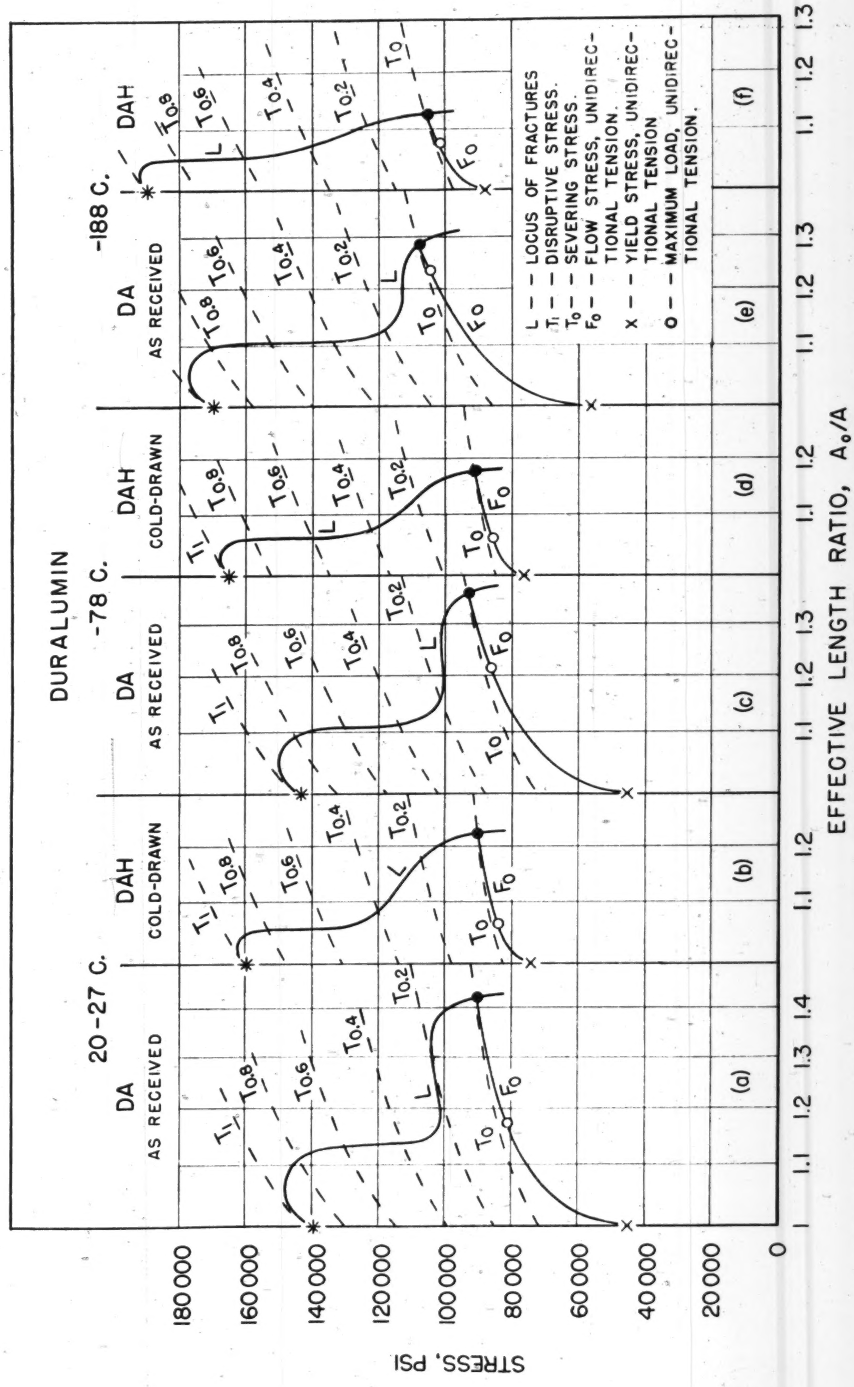


FIG. 12.—Influence of Plastic Deformation on Technical Cohesive Strength of Duralumin at Three Different Temperatures.
]

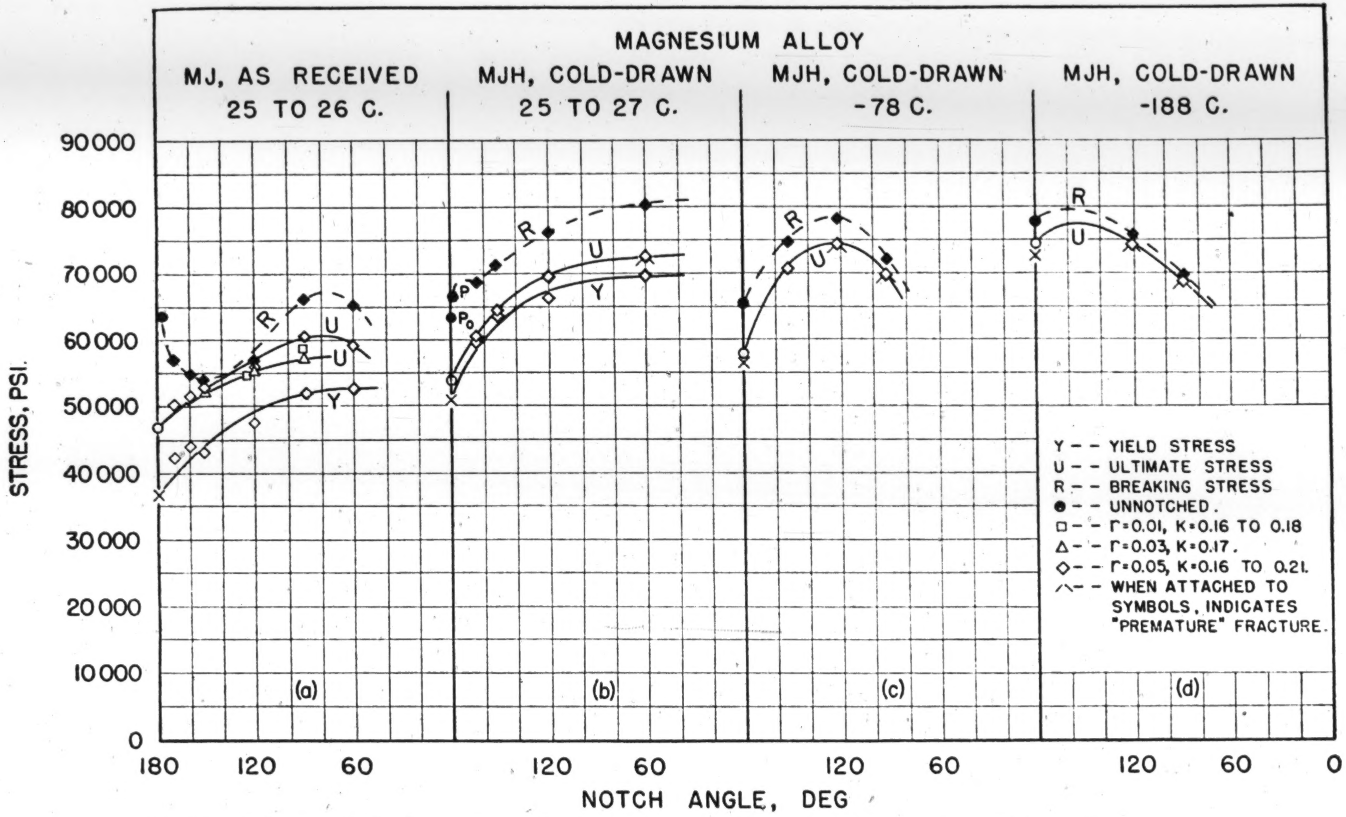


FIG. 13.—Influence of Notches on Strength of Specimens of Magnesium Alloys at Three Different Temperatures.

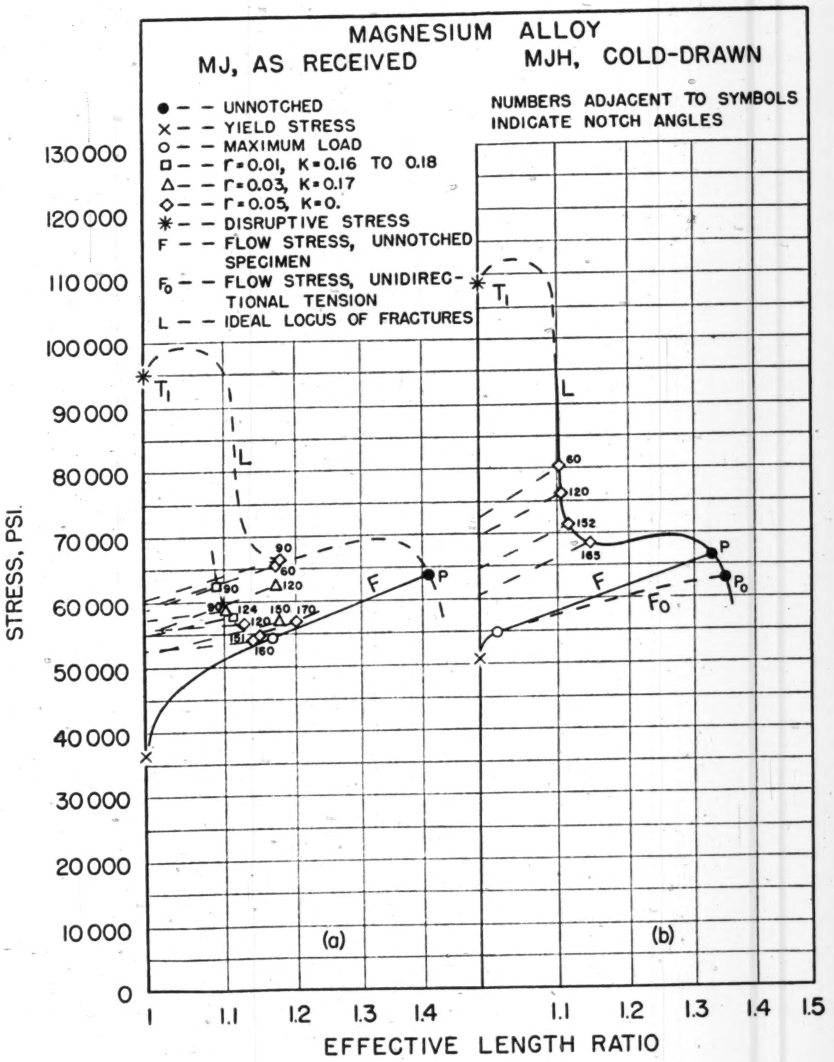


FIG. 14.—Influence of Notches on Breaking Stress and Ductility of Magnesium Alloys at Room Temperature.

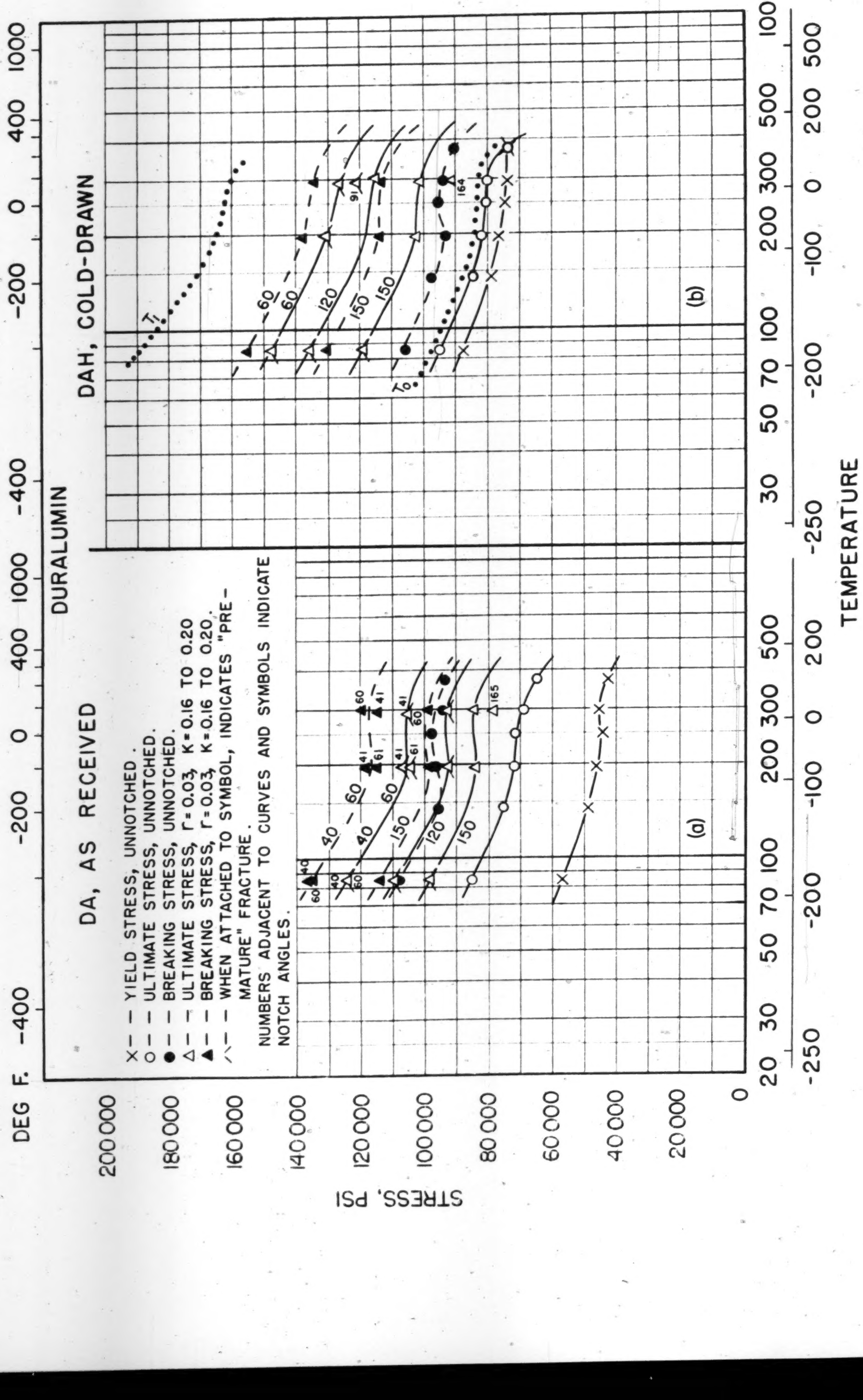


Fig. 15.—Variation of Strength of Duralumin with Temperature.

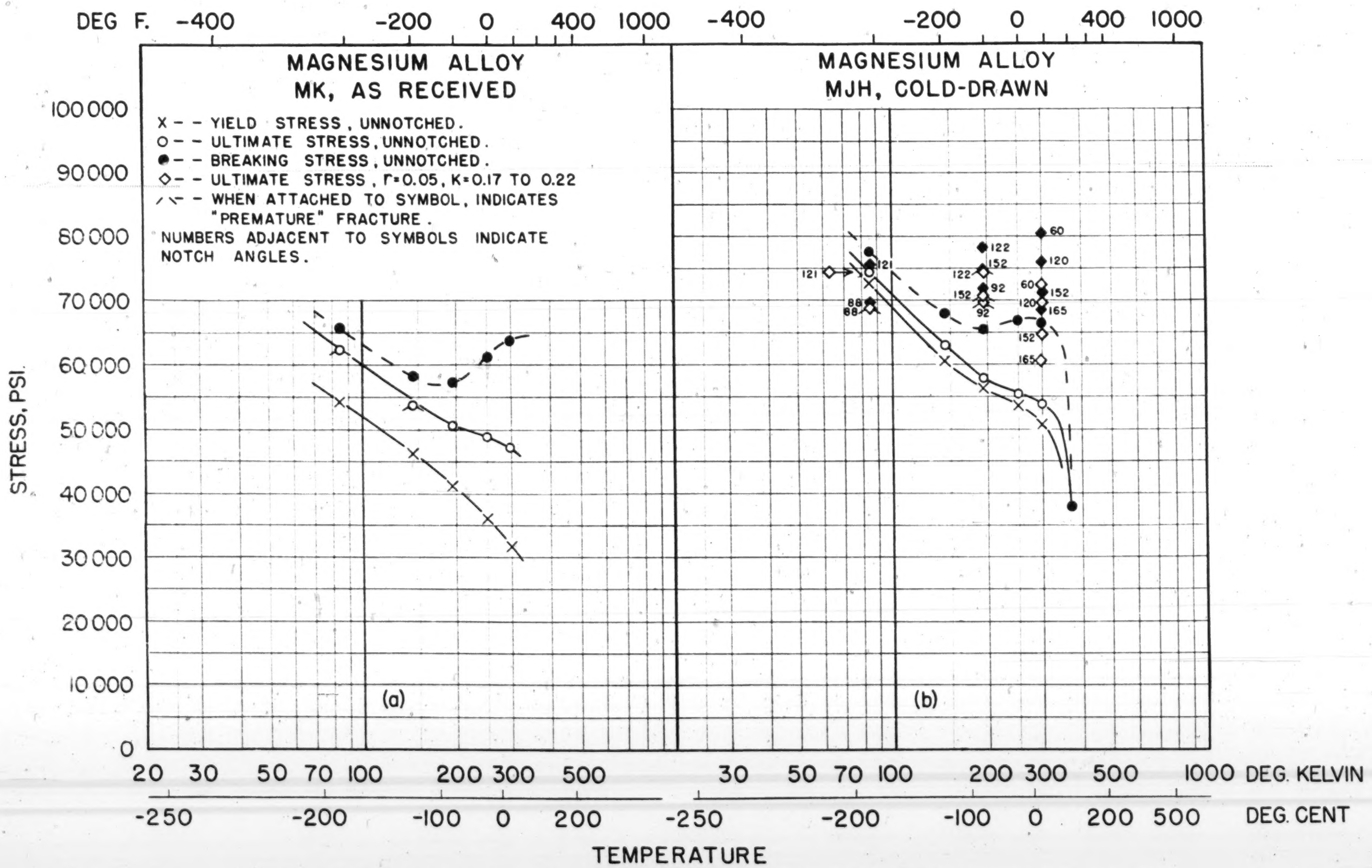


FIG. 16.—Variation of Strength of Magnesium Alloys MK and MJH with Temperature.

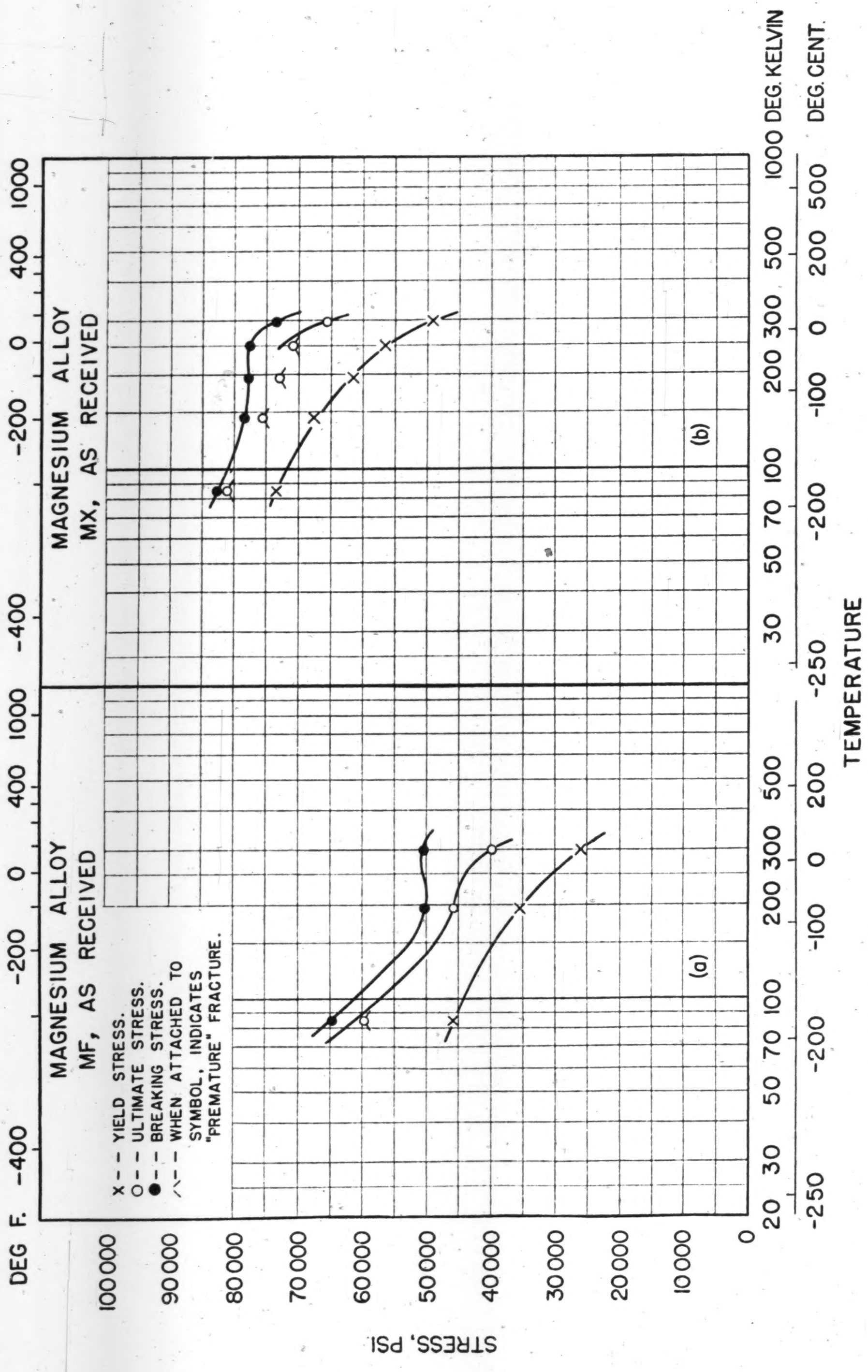


Fig. 17.—Variation of Strength of Magnesium Alloys MF and MX with Temperature.

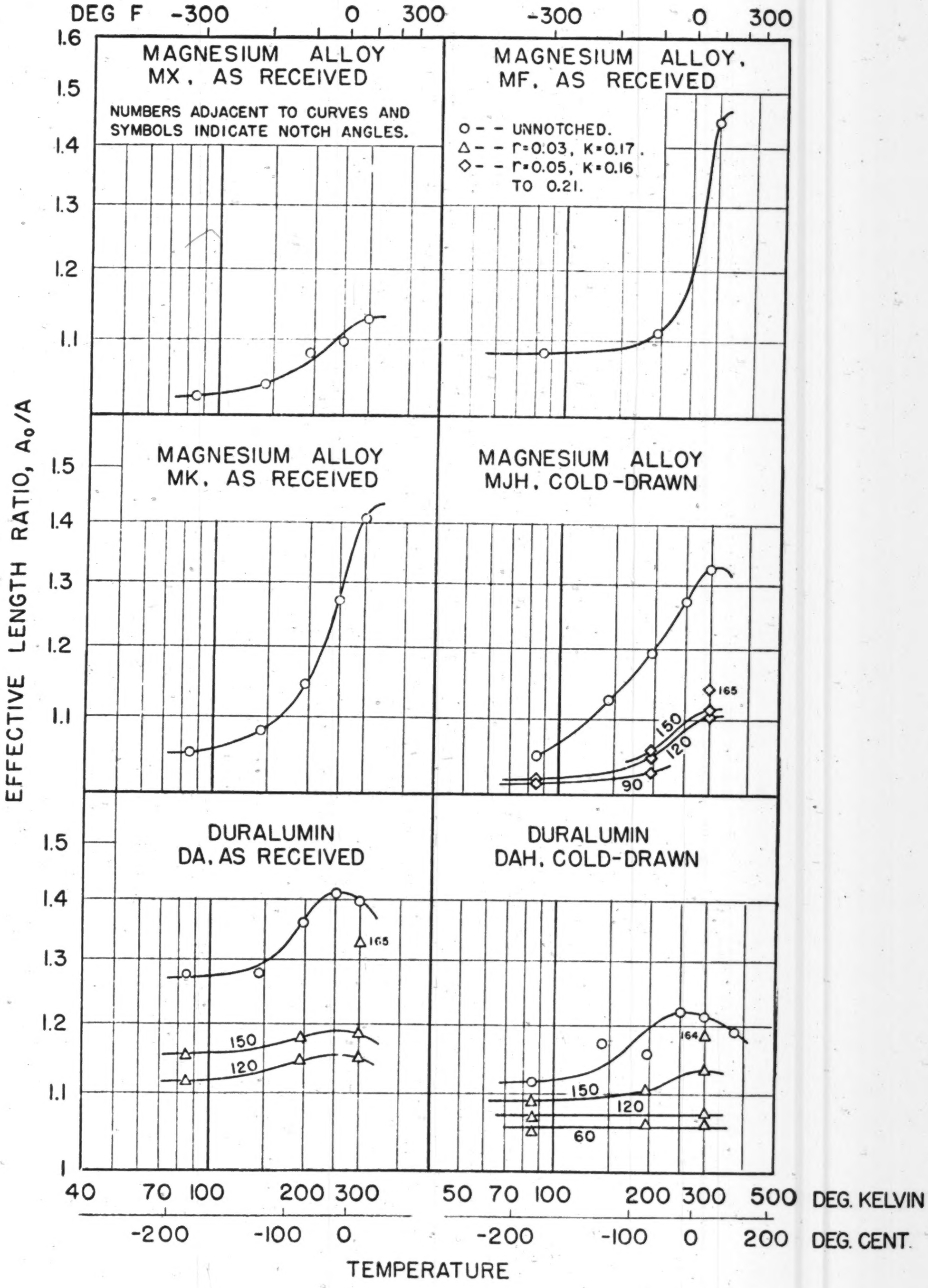


FIG. 18.—Variation of Ductility of Light Alloys with Temperature.

DISCUSSION

Mr. H. F. Moore.[1]—I should like to ask Mr. McAdam a question about the use of the term "technical cohesive strength." Recently one of our graduate students, Mr. Dimitry Morkovin, has been translating a number of articles on this subject which have issued from Russian and German laboratories. In these articles the "technical cohesive strength" is said to be reached whenever there occurs fracture without appreciable plastic elongation. As I understand it, Mr. McAdam does not use the term in this way, but expresses technical cohesive strength in terms of the relative values of the three principal stresses which exist in the specimen at fracture. Do I understand him correctly?

Mr. D. J. McAdam, Jr.,[2] (*author's closure, by letter*).—As the breaking stress varies with the combination of principal stresses, the technical cohesive strength cannot be represented by a single stress value at fracture, whether or not the fracture was preceded by plastic deformation. The *technical cohesive strength* comprises an infinite number of *technical cohesion limits*, each corresponding to a specific combination of the principal stresses. Moreover, temperature and speed of deformation affect the technical cohesive strength about as much as they affect the flow stress. The *initial* technical cohesive strength, therefore, cannot be completely represented by the stress at a brittle fracture, however such a fracture may be obtained. The initial technical cohesive strength for a specific temperature and speed of deformation may be represented by a curved surface in a diagram with the three principal stresses as coordinates. For a ductile metal, this curved surface must be inside the surface representing fracture after the variable plastic deformation, but outside the surface representing yield.

---

[1] Professor of Engineering Materials, University of Illinois, Urbana, Ill.

[2] Metallurgist, National Bureau of Standards, Washington, D. C.

EVOLUTION OF TEST SPECIMEN FOR NON-FERROUS CASTINGS

By A. J. Smith[1]

Synopsis

Brought about by various inconsistencies when used as a measure of metal quality, the integrity of certain current "standard" test specimens for cast materials has been questioned by both producers and consumers.

This paper reviews the historical development of several prescribed specimens, especially those for cast tin bronzes and related alloys.

The specimens considered are shown to be inadequate as true "measuring sticks" since they frequently lead to deceptive results, and do not find justification based on a logical development background.

Design and adoption of specimens according to sound metallurgical principles is advocated.

The selection of suitable test specimens from which the properties of metallic materials may be determined has long been of interest. Proper sampling is a very real problem, and many factors must be taken into account in securing a sample which may be considered representative. In many cases, representative samples may be secured very simply, as in the case of structural shapes and bar stock. In other cases, more particularly in castings, it would be very hazardous to state that the test specimen is truly representative of the part without making a destructive test of the part itself. Unfortunately, a leading difficulty in production of a suitable test specimen lies in the conflict of opinion between producer and consumer. The term "unfortunately" has been used not because the two groups are at variance on the theoretical grounds of proper sampling, but because each has formulated an opinion without a proper background on the subject.

History of Development of Specifications

In the early years of the last century, both in this country and abroad, physical properties were of interest chiefly to the scientist. The consumer showed little interest in physical tests.[2] From this early work, however, data were compiled on the different materials available on which engineering formulas could be based. Mild interest was taken in tensile strength by some engineers, but it was not until Kirkaldy's work in about 1860 that the importance of such a factor as ductility was impressed on engineering minds. From this time on, the testing of materials took great strides with consequent assembling of many data and development of most of our present engineering formulas. At the same time the desire to check the new formulas arose among the consumers, especially in the Army Ordnance Department. This led to the installation of a 400-ton Emery machine at Watertown Arsenal in 1875, largely through the instrumentality of Col. Theodore T. S. Laidley. Many destructive tests were made on this machine, by which the Ordnance Department could check the quality of purchased materials. With publication of these data there was a trend among other consumer interests to specify grades of materials purchased. Chief among these were the railroads.

---

[1] The Lunkenheimer Co., Cincinnati, Ohio.

[2] Attention is called to the work of a special committee of the Franklin Institute on the Explosions of Steam Boilers which reported its findings in 1837. In the study of materials failures a testing machine was constructed and described (Journal, Franklin Institute, February, 1832) and is still preserved in the Institute museum. In that period boiler explosions were prevalent and costly both in lives and property and extensive investigations were made both in this country and abroad to determine the causes of failure. While materials failures were frequent, most attention was paid to the need for indicating and control devices, and there was no evident attempt at materials specifications. The privilege of examining these reports was made possible through the courtesy of G. H. Clamer, The Ajax Metal Co.

With consumer specifications to meet, it was incumbent on the producer for competitive reasons to improve his methods or alloys to meet the specification. In this connection and at this time (about 1880) a board was appointed to survey the potentialities of various materials including alloys of copper, tin, and zinc (**1**).[3] Tests were made on transverse test bars 1 in. square, 22 in. between supports. Tension tests specimens 0.798 in. in diameter were machined from the transverse bars of both ferrous and non-ferrous metals.

The trend here is clearly evident. The work of Kirkaldy and the earlier works of Hodgkinson, Barlow, and others established the requirements needed for engineering design calculations. Elaborate and what were considered to be fairly precise formulas were worked out, on the basis of the data obtained, which found their way into engineering text books and eventually into building and other codes. Nevertheless, repeated failures led to the study of full-scale service parts. For example, the collapse of the Ireland Building in 1895 occasioned tests of ten different cast iron columns, including those from the building, which ultimately showed Gordon's formula to be incorrect on both theoretical and practical grounds the calculated strength of the columns in the building being 128 per cent greater than their actual strength. Since this and many other engineering formulas are empirical, their accuracy depends on the accuracy and reproducibility of the measurements of the properties of the material. In the ten columns tested by the Building Department of New York City, breaking loads varied from 22,700 psi. to more than 40,000 psi.

These experiments and failures led engineers to be very skeptical of all materials data and to insist on tests of the parts to be employed or of representative samples of test coupons removed from the parts.

Unfortunately, metallurgy had not developed at this period from an art to a science. The metal producer, whether foundry or mill, with no intimate knowledge of the material being produced, was unable to advise or criticise the efforts of the engineer or scientist working on these problems. Furthermore, he was probably not even remotely interested. The engineer chose his samples more or less blindly and performed extensive experiments and devised mathematical tricks with no knowledge of whether the material was good, bad, or indifferent. As an example, to return to studies of columns, Hodgkinson's experiments on which Gordon's formula was based, were performed on Low Moor, Yorkshire No. 3 iron, said to be good iron, not very hard, which showed a tensile strength of 14,535 psi. (**2**). The lowest strength iron allowed in the first standard specifications for cast iron of the A.S.T.M. adopted in 1905 was 18,000 psi. It would be difficult for a modern foundry to produce an iron as weak as Hodgkinson's. Had there been competent metallurgists in that day to give proper advice, much future grief would have been avoided. Actual competence was not attained until the turn of the century, but scientific control in the gray iron foundry had scarcely come twenty years later.

---

[3] The boldface numbers in parentheses refer to the reports and papers appearing in the list of references appended to this paper, see p. 635.

DEVELOPMENT OF BRONZE TESTING REQUIREMENTS

As with cast iron, little was known of non-ferrous alloys until long after their application in engineering design. In fact, no interest was displayed in non-ferrous materials by the A.S.T.M. until 1911 with the formation of Committee B-2 on Non-Ferrous Metals and Alloys (Committee B-5 on Copper and Copper Alloys Cast and Wrought resulted from reorganization of B-2 in 1929).

By the time of the organization of Committee B-2 the test bar situation for non-ferrous alloys was rather hopelessly muddled. Each producer had his own favorite bar, if a bar was made at all. In view of the earlier history, it was natural that the consumer should want a test on a coupon taken from or cast integrally with the casting contracted for. The development of the new science of metallurgy went unheeded by the engineer. Nevertheless, the foundryman was learning to control his product and to place faith in the bar he had developed on the basis of good foundry practice and good metallurgy. In many cases the consumer was well satisfied with the result. Critical discussion in the technical press pointed out the misleading results often obtained from the integrally cast bar (3). Other work also appeared governing the design of bars, especially that of Jones (4), Karr (5), Webbert (6), and Skillman (7).

Conflict of opinion between engineer, foundryman, and metallurgist might have been eliminated at this time but for failure of manganese bronze castings and forgings at the Catskill Aqueduct in 1914. It was recognized that for this material, at least, no adequate test bar had yet been devised. This failure led to withholding of standard specifications for high-strength brass and bronze rods scheduled for completion in 1915, in discussion of which G. K. Burgess of the National Bureau of Standards remarked, "It would appear that the knowledge generally available to engineers responsible for designing structures into which non-ferrous alloys enter is all too meager" (8).

In the period commencing around 1910 much attention was paid to the method of producing test bars, as noted above. The main points involved were: (1) the separately *versus* the integrally cast bar; (2) the machined *versus* the cast-to-size bar, and (3) the sand-cast *versus* the chill-cast bar. Many leading foundrymen were in favor of the integrally cast bar. Referring to Outerbridge's work (3) on the coupon test, Jesse Jones wrote, "It is rather gratuitous to call the integrity of such tests into question. . . ." (4). Jones performed a number of tests on manganese bronze and "red brass" (composition not stated but presumed to be 85–5–5–5). The test bar patterns represented those currently used by a number of leading manufactures. Jones concluded that the best sand-cast bar was one similar to a steel coupon with a heavy over-all riser. In view of the high shrinkage of manganese bronze, this conclusion was possibly correct and the present manganese bronze specifications call for a keel block casting although the keel block specimen is at present under question, especially in England. For red brass, however, his conclusion was not borne out by his data, the best tensile strength being shown by a simple cast-to-size bar with a riser at the far end from the gate. Bars simulating integrally cast bars were generally inferior.

The Webbert Bar:

In 1914 Webbert (6) described his method of attaching test bars to a casting, the bar being cast approximately to size and attached to the casting by a thin gate the full length of the specimen as shown in Figs. 1 and 2, claiming this method specially suitable for 88-10-2 castings. If the bar could be placed in the parting line, the pattern could be put on the plate. Otherwise it was a simple matter to place a suitably designed core.

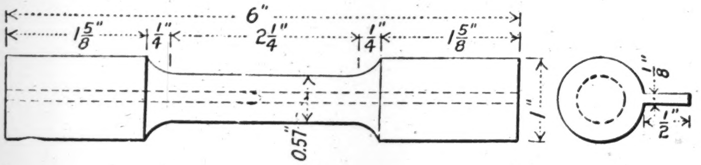


FIG. 1.—Test Specimen for 88-10-2 Casting, as Cast.

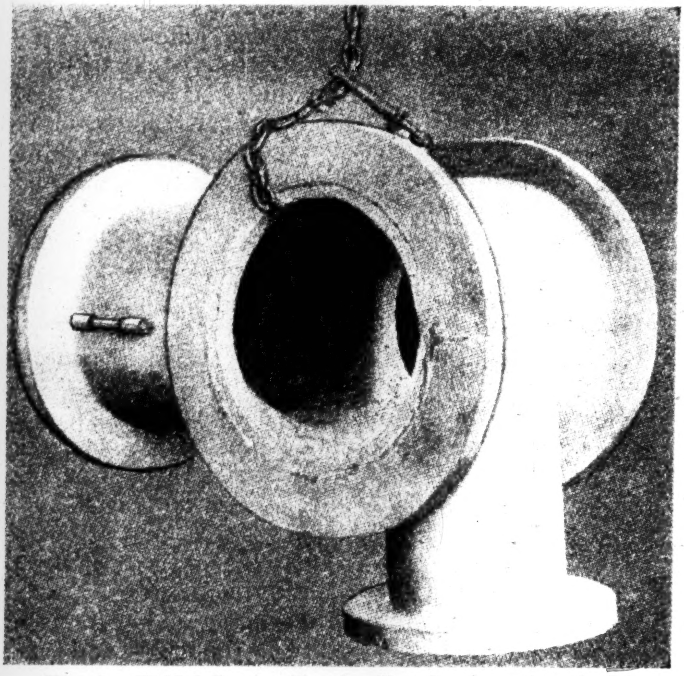


FIG. 2.—88-10-2 Casting Showing Test Specimen Attached.

It is interesting to note that Webbert gave data in which for a large valve body the body wall showed a tensile strength of 25,800 psi. and an elongation in 2 in. of 13 per cent, for the flange a tensile strength of 23,650 psi. and an elongation of 11.0 per cent, and for the cast-on bar a tensile strength of 40,000 psi. and an elongation of 40 per cent. The bar could hardly be called representative of the casting.

An extensive investigation was carried out by the National Bureau of Standards in cooperation with the American Institute of Metals on the general properties of 88-10-2 with one of the purposes the establishment of a suitable standard test bar. This investigation resulted in the reports of Karr (**5, 10**) and Rawdon (**9**) to the American Institute of Metals and in the report of the National Bureau of Standards (**11**). The results on test bars were not particularly conclusive and the chief outcome of the investigation was the oxidation theory of causes of porosity in bronze, since shown to be entirely erroneous.

When the A.S.T.M. Tentative Specification for the Alloy: Copper, 88 per cent; Tin, 10 per cent; Zinc, 2 per cent (B 10 - 15 T)[4] were established in 1915, a bar similar to the Webbert bar shown in Fig. 3 was made mandatory for all castings on which it could be applied. On other castings the method of test bar production was as agreed to by producer and purchaser. The specifications were adopted as standard in 1918 (B 10 - 18).[5]

The Crown Bar:

That the Webbert bar was not entirely satisfactory is evidenced by the fact that the whole test bar question was again reviewed by Subcommittee III on Sand-Cast Metals and Alloys of the A.S.T.M. Committee B-2 on Non-Ferrous Metals and Alloys in 1922 (12) and much experimental work was done on a bar corresponding in its general features to that now known as the Crown bar, with thin gates along the length of the grips but leaving the gage length free, unlike the Webbert bar with its fin-gate the whole length. No report was made of the data obtained on these cooperative investigations but note of the progress of the work was taken by Jones in discussion of Dix's paper on non-ferrous specimens (13) that at that time chief attention was being given to the bar of the Crown type attached to a *flat* reservoir plate.

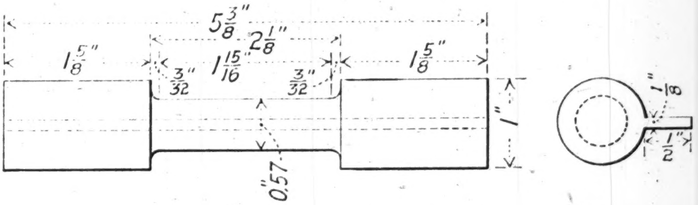


FIG. 3.—Test Specimen of A.S.T.M. Specification B 10.

The A.S.T.M. Bar:

Whatever the verdict of the investigating committee, when A.S.T.M. Tentative Specifications for 88-8-4 Copper-Tin-Zinc Alloy: (B 60 - 26 T),[6] Steam Bronze (B 61 - 26 T),[7] and Composition Brass (B 62 - 26 T)[8] were proposed, the bar described in B 10 - 18 was modified to the extent of adding a plate approximately 1 by 4 by 6 in. to which the bar was attached throughout its length by a fin-gate $\frac{5}{16}$ in. thick as shown in Fig. 4. The fin-gate on the B 10 - 18 bar was $\frac{1}{8}$ in. thick and $\frac{1}{2}$ in. wide at the grips, the width not being specified in the new pattern until 1941. Whether there was complete faith in this new pattern cannot be stated, but suffice it to say no change

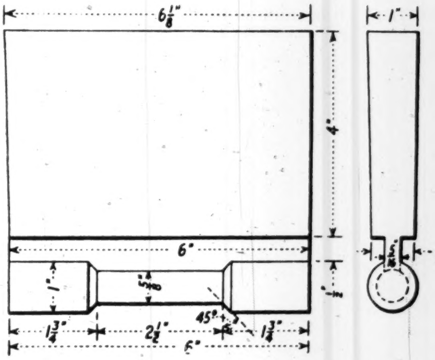


FIG. 4.—Test Specimen Coupon of A.S.T.M. Specifications B 60.

---

[4] 1915 Book of A.S.T.M. Standards, p. 550.

[5] 1918 Book of A.S.T.M. Standards, p. 447.

[6] *Proceedings*, Am. Soc. Testing Mats., Vol. 26, Part I, p. 701 (1926).

[7] *Ibid.*, p. 705.

[8] *Ibid.*, p. 709.

was made in the B 10 - 18 pattern until 1934 when these specifications were withdrawn as being covered by Specifications B 60 - 28.[9]

An interesting point develops in examining requirements of A.S.T.M. Specifications B 10 and B 60, B 61, B 62. The Webbert bar of B 10 - 18 was required to be an integral part of all castings to which it could be applied. The modified bar with plate attached of the later specifications B 60, B 61, and B 62 was mandatory until 1941 when the sense was changed to recommended. In a casting to which it was practicable to attach a bar, according to the requirement of the specifications, not only the bar but its accompanying plate had to be attached. No method of gating is prescribed in A.S.T.M. specifications but in U. S. Federal Specification QQ-M-151a the gating is clearly prescribed. From this provision it is obvious that the test bar is no more representative of the casting to which it is attached than if it were cast separately. The new A.S.T.M tentative specifications which replace the earlier B 60, B 61, and B 62, namely, A.S.T.M. Tentative Specifications for Tin-Bronze Castings (B 143 - 42 T),[10] and for Leaded Red Brass (B 145 - 42 T),[11] and also others in which this same test bar is recommended, namely, A.S.T.M. Tentative Specifications for High-Leaded Tin-Bronze (B 144 - 42 T),[12] for Leaded Yellow Brass (B 146 - 42 T),[13] and for Leaded Nickel-Brass (B 149 - 42 T),[14] omit all reference to attachment of the bar to the castings.

From a cooperative research investigation of the Non-Ferrous Ingot Metal Institute and the National Bureau of Standards commencing in 1930, Gardner and Saeger (14) reported that the fin-gate type bar of A.S.T.M. specifications showed adverse structural development as a result of the fin-gate and over-all riser with a consequent lack of uniformity in physical properties. This report showed better properties in a cast-to-size bar with a single riser at the far end from the sprue, described a year earlier by Parsons (15). Of interest was a remark in discussion of Parson's paper by St. John, "The whole matter of test bars, it appears to me, is one which should receive a thorough housecleaning. I do not know who should do it but it is overdue." One is reminded of Mark Twain's comment on the weather, that people are always talking about it but no one ever does anything about it.

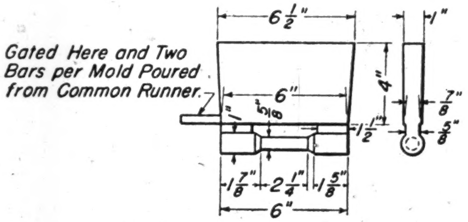


FIG. 5.—Test Specimen Coupon of U.S. Federal Specification QQ-M-151a Fig. 10a.

Quite recently a report was made to Subcommittee X on Copper-Base Alloys for Sand Castings of A.S.T.M. Committee B-5 on Copper and Copper Alloys, Cast and Wrought by Curran, Bolton, Wolf, and Martin on "Studies of Machined *versus* As-Cast Test Specimens for Copper-Base Alloy Sand Castings (16). Comparative tests were reported on methods of casting of Webbert, Crown and other types of bars in general use. The opinion was advanced that the present bars specified by the A.S.T.M. as Webbert, and by the Navy as Crown (see Fig. 5), are not properly designed from a metallurgical viewpoint. An alternative bar was proposed by one of the reporters which was purported to represent not only an economical bar to produce but also one conforming to good foundry practice. This bar, designated in the paper as LTB-1, is at present under consideration by the A.S.T.M. as an alternative to the Webbert bar and has been included as an Emergency Alternate to the specifications in question.

---

[9] 1930 Book of A.S.T.M. Standards, Part I, p. 660.
[10] 1942 Book of A.S.T.M. Standards, Part I, p. 1332.
[11] *Ibid.*, p. 1340.
[12] *Ibid.*, p. 1336.
[13] *Ibid.*, p. 1344.
[14] *Ibid.*, p. 1356.

The foregoing in general covers the history of the present prescribed test bar. Heretofore a producer need not have followed the A.S.T.M. requirement (later recommendation) unless required by the purchaser. At present, however, practically all of these castings are being manufactured to Government specification with no option on the part of the producer. Hence, the producer is considerably more interested in a properly specified bar than he has been in the past. It therefore seems desirable to examine the historical record somewhat critically, as well as to pick the flaws in the present specifications, to see whether some help can be brought forward in this controversial matter.

PURPOSE OF A TEST BAR

There are certain practical principles which must be borne clearly in mind in any discussion of this problem. It is the desire of the engineer to know exactly the quality of the material in a particular section. But no test bar that could be conceived would give him this answer. The only possible test which would be indicative would be a test of the part under the conditions for which the part is designed. If it is a bearing, then the finished bearing must be tested to destruction under its shaft load. If it is a valve for hydrostatic pressure, then the finished valve must be tested to destruction under hydrostatic pressure. Only these tests will tell anything of the quality of the material in the part or the adequacy of the design. A test bar cannot do this. It can only tell the quality of the metal as it goes into the mold. In the development of the integrally cast coupon, it always has been assumed that the bar would show either inadequacy of design or, on the assumption that the design is adequate, the qualities of the metal in the casting. These assumptions in many cases have been wholly unwarranted—else failures of the type shown in the Ireland Building or the Catskill Aqueduct would never have occurred. The integrally cast bar will show only that the metal in the bar itself was properly or improperly melted, cast, and fed.

If the test bar cannot show adequacy of design or adequacy of feeding in a casting, what can it show? The only thing it can show is, as stated above, the quality of the metal as it goes into the mold and the potentialities of the metal *if* the design and gating practices are correct. The test bar should be a true measuring stick of this quality. The question is whether the present test bar is such a measuring stick.

A.S.T.M. BAR AS A PROPER STANDARD

The present design of the A.S.T.M. bar was arrived at in a rather circuitous fashion. In spite of being so-called, it is definitely no longer the Webbert bar. The Webbert bar was designed to be attached to a casting by means of its fin gate. Its intent was to show the quality of metal in the casting near to the point of attachment. Since the new tentative specifications do not even mention the casting, obviously the intent is far removed from Webbert's, let alone having its own riser attached which would certainly indicate some other purpose than to show the quality of the section to which the bar is attached. Actually, there was never a Webbert bar, but only a Webbert gate.

Dix (13) has described experiments performed at McCook Field in which bars were attached to flat rectangular plates by means of this Webbert gate. The most uniform results were obtained when the plate was placed above the bar to act as a riser. However, when the plate was placed horizontally, "the methods were not experimented with further because the results were so high as to be misleading to designers if used for specifications values." This observation has been verified on repeated occasions, most recently by Curran in the committee report last year. But this was the method of attachment advocated by Webbert, that is, gated in the parting line.

The test bar question should have been cleared up by the work of the Bureau of Standards in 1914 and 1915. The issue became confused, however, since improperly melted metal afforded no good data for comparison. The Bureau recognized this fact and made an investigation of melting practice. Most unfortunately, a test bar was developed which would make both good and bad metal give comparable and uniform results, or at least such must be the supposition, for we know today that the metal from which the test bar data were gathered was improperly melted. Dix's (13) bars attached to horizontal plates, which were thrown out because of excessively high results, showed properties which would be considered barely normal with present-day good foundry practice. Most of the bars, including one specimen of the recommended pattern, would be rejected under the present specifications because of low elongation.

CRITERIA FOR TEST BARS

The various points involved in the production of castings and the adequacy of test bar design to show their qualities are touched on here:

1. *Melting Atmosphere.*—Melting atmosphere affects the quality of the metal. An improper atmosphere will cause the metal to be deficient in strength and is a frequent cause of leakers in pressure castings. The test bar should clearly show gassing of the metal, both in lowering of physical properties and poor fracture, and should in no way disguise a gassed condition through accelerated freezing (chills), high head pressure, etc. This was a shortcoming of the Bureau of Standards' work.

2. *Pouring Temperature.*—The pouring temperature of a casting must be governed by its section size to produce a proper solidification with good feeding possibilities and without excessively coarse grain structure. The test bar as a casting likewise should be poured at its best casting temperature which will have no necessary relationship to the temperatures for pouring the castings it represents. The temperature should not be so low as to obscure the effect of gassing, which temperature may be proper for castings of heavy sections, nor so high as to be excessively coarse grained, which temperature may be proper for castings of very light section.

3. *Sand.*—The test bar should not be affected by the quality of the sand. Many castings are cored at their critical sections, and permeabilities vary markedly with the class of work. Metal from the same furnace may be poured into a number of different sands, green, dry, core, etc. Metal for test bars should be poured in that sand which would contribute the least variation in properties. This may or may not be

the sand in which the castings are poured. As stated above, no excessive effect of chill should be produced by the sand chosen. However, since the metal must meet a general specification, it may be as well to specify the sand in which all test bars are cast and thus avoid any question that may arise because of differences in procedure. Since the tin and leaded tin bronzes are cast chiefly in green sand this brief requirement should be sufficient.

4. *Gating.*—If the metal is properly melted and poured, the chief factor contributing to the acceptance or rejection of castings is the gating system employed. Frequently the foundryman is defeated on the drawing-board in properly gating the casting. This is especially true in the jobbing foundries. It is beyond the power of any test bar to show whether a casting is properly gated or properly designed. Hence, it must be made sure that the test bar is properly gated in order to show the intrinsic properties of the metal irrespective of the casting. The gating involves not only proper feeding but also freedom from turbulence, proper skimming, etc.

5. *Cooling.*—The test bar should be allowed to cool at a normal rate in the mold, unaffected by excessive masses of hot material such as excessive risers, etc. The risers should be of sufficient size and be so placed as properly to feed the casting but no more.

DISCUSSION OF A.S.T.M. AND FEDERAL BARS

It is of interest to see in what ways the present A.S.T.M. and Federal bars compare with respect to the factors described above.

1. *Melting Atmosphere.*—Uniformity of results with the A.S.T.M. bar independent of melting atmosphere leads one to wonder whether the A.S.T.M. bar is capable of distinguishing improperly melted metal. A suggested mechanism is that with the heavy feeding head employed the cooling of the specimen attached permits the escape of rejected gases up into the riser through the pronounced directional solidification that would result from the heavy riser and rather wide gate, half the thickness of the bar. If this mechanism is true, and it seems a likely explanation, then the purpose of the test bar for showing metal quality is defeated by the fin gate. This objection is overcome by the use of the Crown bar in which the reduced section is entirely surrounded by sand.

2. *Pouring Temperature.*—As regards bronze test bars, the A.S.T.M. specifications are not specific on pouring temperatures with the exception of the statement, "The bars shall be cast from the first metal poured from the melt."[15] In the case of large castings, the proper temperature for test bar pouring could be attained readily, but in the case of small castings requiring a high pouring temperature, the temperature might be much too high for the test bar.

3. *Sand.*—The A.S.T.M. specifications only require that the test bar be poured in sand and that it should not be chilled. As stated above, it might be desirable to require the use of green sand for the sake of uniformity.

4. *Gating.*—In earlier work on the study of test bars little was done to skim the metal of slag or dross in the gating or to eliminate turbulence. This undoubtedly has contributed in certain instances to erroneous results. It is up to the foundryman to see that clean metal goes into the mold, and this need not be a part of the specifications. However, in the publication of data on the subject, such data as might be affected by slag or other inclusions should not be submitted.

---

[15] 1942 Book of A.S.T.M. Standards, Part I, p. 792.

Under atmosphere it was pointed out that the fin gate the length of the bar was undesirable and that the Crown bar was a better solution. However, if there is to be a riser over each end, or even a single one as in the case of the Crown bar, there is no good reason for attaching it as it is now, in view of the greatly added expense involved. In most foundries the Crown bar is difficult to mold and to pour and its merits hardly justify such difficulties. By making separate risers for each end cylindrical in form, the same results are achieved very much more simply. The point of attachment and dimensions of the gate in the Navy bar are more than unduly restrictive. If limiting conditions were set up that the foundryman could work *to* (for example, green sand, risers at each end, a pouring temperature control), it would be utterly impossible to produce a bar that was too good—Mr. Dix to the contrary notwithstanding. Hence, the ideal would be to fix these limits reasonably and impose no further restriction if the restriction only makes for added cost. The only purpose of any of the restrictions should be to prevent the up-grading of a bad lot of metal, and any restriction that would cause good and bad metal to give similar results is very definitely objectionable. Likewise any restriction which would increase the production cost without commensurate benefit is unwarranted. The fin gate on the A.S.T.M. bar, the prescribed ingress gate and single flat riser in the Federal and Navy bars, are objectionable for these reasons.

MACHINED *versus* UNMACHINED BARS

Nothing has been said thus far concerning machined *versus* unmachined test bars of sand-cast alloys. This point has also been debated for many years. There should be little debate if cognizance is taken of the metallurgical principles involved. In any metal or alloy cooling through the freezing range, impurities, gases, etc., are concentrated in the remaining liquid. The portion first solidifying is relatively free from such, unless the metal is extremely poor. With this impurity concentration at the center, the center will constitute a zone of weakness. Hence, the machined bar theoretically will be weaker than the unmachined. If the metal is uniformly good and cast into a well-designed test bar mold, the difference between machined and unmachined bars will be negligible. If, however, the metal is inferior, the worse it becomes the greater will be the difference between the two. It is believed that the machined bar has been specified because of the amount of experimental work in the past performed on poorly melted metal. Because of the upgrading of poor test bars by testing them unmachined it has been thought wisest to specify machining. This would appear to be one of the unfortunate penalties the first class foundryman must pay because of competition in the field of his less enlightened brothers.

CONCLUSIONS

A review of the history of development of the bronze test bar reveals that the present bars (A.S.T.M., Federal and Navy) have become accepted on no very sound premises and from many unsound data. The present A.S.T.M. and Navy bars started out simply as a convenient method for attaching a bar to a casting, and have ended up as separately cast bars with very carefully dimensioned over-all risers in the feeding of which great faith is placed. The data presented, unfortunately, are about the worst possible defense of the bars. The bars have been brought to fruition as a hodge-podge of ideas which can be defended on neither historical nor theoretical grounds. They are an expense, a burden, and almost universally an object of controversy among foundrymen.

It would appear to be time for our standardization societies to get together and develop a bar which would represent just what a test bar should be—a reasonable and economical sample which will represent the metal from which a lot of castings are to be made. The design of the present bars has largely resulted from the dictates of the consumer group with not too much evidence of thorough grounding in either metallurgy or foundry practice, and it must be admitted that the foundrymen have aided and abetted with little regard for the metallurgy involved.

A symposium on this subject is advocated, with the foundrymen and metallurgists proposing a suitable bar with adequate supporting data which the consumers are privileged to criticize just as freely as the present bar has been criticized. The conclusions of such a symposium should lead to a reasonable solution to the problem.

REFERENCES

(1) Report of the U. S. Board Appointed to Test Iron, Steel, and Other Metals, Vol. II, Washington (1881).

(2) *Philosophical Transactions of the Royal Society*, London (1840).

(3) A. E. Outerbridge, Jr., "Integrity of Tests of Metals," *Journal*, Franklin Institute, Vol. 170, p. 206 (1910).

(4) Jesse L. Jones, "Test Bars for Non-Ferrous Alloys," *Transactions*, Am. Inst. Metals, Vol. 6, p. 173 (1912).

(5) C. P. Karr, "Report of Work Done at the Bureau of Standards, Pittsburgh, Pa., on Non-Ferrous Alloys During 1913," *Transactions*, Am. Inst. Metals, Vol. 7, p. 252 (1913).

(6) L. P. Webbert, "Study of the Strength of Non-Ferrous Castings: Comparison of Different Test Specimens," *Proceedings*, Am. Soc. Testing Mats., Vol. 14, Part II, p. 145 (1914).

(7) V. Skillman, "The Non-Ferrous Alloy Test Specimen Question," *Transactions*, Am. Inst. Metals, Vol. 7, p. 360 (1913).

(8) G. K. Burgess, "Discussion of Report of Committee B-2," *Proceedings*, Am. Soc. Testing Mats., Vol. 15, Part I, p. 139 (1915).

(9) H. S. Rawdon, "Standard Test Specimen of Zinc-Bronze: Cu 88; Sn 10; Zn 2," *Transactions*, Am. Inst. Metals, Vol. 9, p. 60 (1915).

(10) C. P. Karr, "Report of a Series of Comparative Tests of Zinc-Bronze Standard Test Bars," *Transactions*, Am. Inst. Metals, Vol. 10, p. 77 (1916).

(11) C. P. Karr and H. S. Rawdon, "Standard Test Specimens of Zinc-Bronze," *Technical Paper No. 59*, Nat. Bureau of Standards, 1915.

(12) Report of Subcommittee III of Committee B-2 on Non-Ferrous Metals and Alloys, *Proceedings*, Am. Soc. Testing Mats., Vol. 23, Part I, p. 177 (1923).

(13) E. H. Dix, Jr., "Methods of Casting Test Specimens of Gun Metal," *Proceedings*, Am. Soc. Testing Mats., Vol. 23, Part II, p. 142 (1923).

(14) H. B. Gardner and C. M. Seager, Jr., "Factors Affecting the Physical Properties of Cast Red Brass," *Proceedings*, Am. Soc. Testing Mats., Vol. 32, Part II, p. 517 (1932).

(15) R. W. Parsons, "Deep Etching of Brass Applied to Gating Problems," *Transactions*, American Foundryman's Assn., Vol. 39, p. 843 (1931).

(16) J. J. Curran, J. W. Bolton, F. L. Wolf, and W. E. Martin, "Studies of Machined *versus* As-Cast Test Specimens for Copper-Base Alloy Sand Castings," *Proceedings*, Am. Soc. Testing Mats., Vol. 42, p. 199 (1942).

(17) Recommended Practice for Non-Ferrous Test Bars and Their Pouring Temperatures, Canadian Department of Munitions and Supply, Sept. 27, 1943.

(18) W. A. Baker, "Test Bars for Non-Ferrous Castings," *Metal Industry*, London, Feb. 25, 1944.

DISCUSSION

MR. G. H. CLAMER.[1]—Mr. Smith has contributed in his paper information of much value for the guidance of Subcommittee X of Committee B-5 on Copper Alloys, of which I am chairman. He has presented an historical story of the evolution of existing test bars and test bar practice. He has clearly disclosed that there is still lacking a proper understanding of the same.

The subject of his paper has been under discussion for many years. In 1912 the Society took its first steps in connection with the study of test bars and test bar practice to be used for determining the properties of copper-base alloys. A small group met at that time for a discussion of this subject. Through the influence of that group the Advisory Committee of the National Bureau of Standards came into being. Mr. C. P. Karr was retained by the Bureau and was assigned to the project of developing satisfactory test bars and test bar practice to be used in determining the properties of copper-base casting alloys. As stated by Mr. Smith in his paper, his work was largely in connection with the study of so-called "gun metal"; namely, 88 per cent copper, 10 per cent tin, 2 per cent zinc alloy.

Mr. Smith has traced historically the evolution of various test bars. The Webbert bar was proposed after Mr. Karr's time and still later the Crown bar and others. I am glad to report that there has been for some time a crystallization of knowledge and opinion indicating that a revision of our present practices is due. The paper is particularly valuable in that it emphasizes the fact that the so-called Webbert bar was originally intended for attachment to a casting, also that it cannot represent the metal in a casting. This fact is becoming increasingly clear to all concerned. The Non-Ferrous Division of the American Foundrymen's Association last year formally went on record with a statement to that effect. Subcommittee X of Committee B-5 went on record as advocating a complete study of test bars and test bar practice as applied to copper-base alloys for sand castings.

Subcommittee X, Committee B-5, in its annual report at this annual meeting, is recommending the revision of the specifications for copper-base ingots for sand castings by proposing that ingots be sold on the basis of meeting physical requirements with less dependence on chemical requirement. This action has stimulated the Non-Ferrous Ingot Metal Institute to sponsor financially an extensive research project at Battelle Memorial Institute, to be devoted to test bars and test bar practice. This project is now under way. It is interesting to note that in a recent publication the British Non-Ferrous Metals Research Association made the statement that standardization of test bars and test bar practice is long overdue. Mr. W. A. Baker of that association recently presented a paper containing one very pertinent statement; namely, that he considers that the best test bar now almost universally used, and having a diameter of only 0.57 in. on the parallel portion, does not discriminate sufficiently well between gassed and degassed metal. He presents emphatic evidence to disclose that in a section of this small diameter the gas is squeezed out of that section because of rapid chilling and is entrained in the shoulder. Such test bars are frequently porous in the shoulders and break in that locality. The author proposes a test bar of larger diameter. A comparison of the present-day small diameter bar with a bar of larger diameter is worthy of extended investigation.

---

[1] President and General Manager, The Ajax Metal Co., Philadelphia, Pa.

I am delighted that this subject has now been brought out into the open. As a result of the Non-Ferrous Ingot Metal Institute research project above referred to, I am quite confident that more satisfactory test bars than those currently in use will be developed. One standard type of bar, having uniform dimensions, cannot reasonably be expected to be suitable for all copper-base casting alloys. We can look forward with much confidence to evolving a test bar and standardized test bar practice that will make possible a true indication of properties.

MR. SAM TOUR.[2]—This paper is a straight-from-the-shoulder talk on the subject of test bars. I might suggest that it be considered as directed against test bars in the copper-base alloy field rather than against the entire non-ferrous field. Committee B-7 has been doing some work in connection with test bars for aluminum, and I believe that the situation for sand castings of aluminum is a little farther along.

I should like to point out what, in my opinion, is a large contributory factor to this situation in connection with test bars for the brass and bronze casting field. I refer to the lack of interest and lack of cooperation among the non-ferrous foundrymen in this country.

If we review the A.S.T.M. specifications and the make-up of the committees, we find that the main driving force in connection with copper-base alloy castings has been the producer of ingot metal and not the foundries that are making castings. A few outstanding men representing foundries making castings are on these committees, but the bulk of the committee membership has been the ingot metal producers and the service departments of the Government. Actually, foundrymen throughout the country are inactive and users of non-ferrous castings, other than Government services, have not been very helpful and cooperative.

For years I have pointed out the need for a little more interest and desire to accomplish something upon the part of the non-ferrous foundrymen, and how the foundrymen have not supported work along these lines and lack a cooperative attitude.

The cooperative work of the Ingot Metal Institute has been excellent. It is high time that the non-ferrous foundrymen in this country woke up to the fact that they are in business, they hope to stay in business, and they should do something to preserve and improve their own business.

MR. WAYNE MARTIN[3] (*presented in written form*).—This paper gives a very interesting history of the evolution of test specimens, much of which was not known to us. We have given considerable thought to this problem and have arrived at some conclusions. They are as follows:

1. A cast test bar can be used only as a test means to insure that the metal was in its proper condition at the time it was poured into the mold.

---

[2] President, Sam Tour & Co., Inc., New York, N. Y.

[3] Assistant Materials Engineer, Materials Lab., Sperry Gyroscope Co., Inc., Brooklyn, N. Y.

2. The cast test bar cannot be used as a means of determining the usefulness of a casting. This must be evaluated by other methods such as radiographic inspection, load deflection or some means of breakdown test.

3. Assuming that the test bar can be used only as a means of determining that metal in the proper condition has been used to pour the casting, then the test bar should be cast in its most simple form that will give the best and most uniform properties for the metal being used. We, therefore, use cast-to-size bars on certain bronzes where these conditions are met, as in 88-8-4 gun metal and in 15 per cent zinc, 5 per cent silicon, silicon brass.

MR. J. W. BOLTON.[4]—A great deal of trouble, as you realize, in the test bar evolution has arisen from the fact that years ago foundrymen did not know how to make sound bronze. When the bars showed variations no one knew whether those variations were due to idiosyncrasies due to design of the test bar or something wrong with the furnace operation or what.

And there is, besides making test bars, a broad research field in the non-ferrous copper-base alloys for foundrymen to study, for example, the effects of section, the effects of design, and so forth. You are getting in this test bar just one phase of a big general problem.

MR. A. J. SMITH[5] (*author's closure, by letter*).—The author appreciates the comments of those who participated in the discussion.

It is not clear with respect to Karr's work when the Webbert bar was first considered for standardization purposes. Webbert and Karr were working on the problem at the same period. The Webbert bar was adopted for A.S.T.M. Specifications B 10 in the same year that Karr's comprehensive report appeared, 1915. It is of interest to note that Mr. Clamer pointed out, in discussion of Webbert's paper at its presentation in 1914, that the Webbert bar was apparently satisfactory for copper-zinc alloys but not for copper-tin.

It is gratifying to learn that work on the problem is again being carried on as a sponsored research project. Great credit is due the Non-Ferrous Ingot Metal Institute for this. The foundrymen and manufacturers should feel a little remiss at not coordinating their effort in this work.

The work of the British Non-Ferrous Research Association should be followed very attentively. It is concerned with the production of sound castings and getting the molten metal in proper condition for yielding soundness if other phases of the foundry practice are correct. To do this a suitable measuring stick is necessary and as Mr. Clamer points out the test bars currently used have been shown to be quite inadequate in this respect.

Mr. Tour is correct in that this paper is directed chiefly against test bars in the copper-base alloy field. Nevertheless even for aluminum alloys much remains to be done. In certain of the aluminum alloys melting procedures are employed to redistribute the expected porosity so that the voids are no longer harmful, yet with no change in the actual density. This calls for such a delicate balance that the test bar may or may not indicate the true condition of the metal. However, as Mr. Tour says the situation is farther along.

---

[4] Director of Metallurgical Research and Testing, The Lunkenheimer Co., Cincinnati, Ohio.

[5] The Lunkenheimer Co., Cincinnati, Ohio.

AN ALTERNATE IMMERSION TEST FOR ALUMINUM-COPPER ALLOYS

By R. B. Mears,[1] C. J. Walton,[1] and G. G. Eldredge[1]

Synopsis

A control test for some aluminum-copper alloys is described. This test consists of alternately immersing specimens of these alloys in a solution containing 57 g. of sodium chloride and 3 g. of hydrogen peroxide per liter at 30 C. A detailed description of the test procedure is given. The effect of several variables, such as concentration and volume of the solution, or change in thickness and heat treating conditions of the test specimens, on the test results is discussed.

For the past eighteen years, the Aluminum Research Laboratories have been using an alternate immersion test in a solution of sodium chloride and hydrogen peroxide as a control test for aluminum alloys (other than the Alclad alloys) which contain copper as the principal alloying agent. This test has proved very useful during its long period of service. In addition, the mechanical features of the alternate immersion unit have been entirely satisfactory. It was, therefore, considered desirable to describe this unit in order that others could benefit from our experience.[2]

The test is used to determine whether one lot of a given aluminum-copper alloy behaves similarly to other lots, and what the effects of various thermal treatments are on the resistance to corrosion of a given aluminum-copper alloy. For these purposes it has proved highly valuable.

This test cannot be considered as an "accelerated corrosion test" as this term is ordinarily used. That is, no attempt has been made to state that x hours exposure in the alternate immersion test is equivalent to y hours exposure to the outdoor atmosphere. Such a correlation in the general case is impossible, since the relative behavior of different alloys varies too widely when exposed in different outdoor locations.

Description of the Test:

During the years the test has been used, it has been improved and modified in various ways. Its present form will be described here.

The apparatus consists of a large, insulated cabinet 97 by 78 in. by 78 in. high (see Fig. 1). In this cabinet two shelves are housed one above the other. Wide slots are provided in these shelves into which glass solution containers can be slid. These glass containers are $5\frac{5}{8}$ by $10\frac{5}{8}$ in. by 3 in. high. They are of Pyrex glass and are made for baking bread.

---

[1] Chief, and Metallurgists, respectively, Chemical Metallurgy Division, Aluminum Research Laboratories, Aluminum Company of America, New Kensington, Pa.

[2] A description of another method of conducting alternate immersion corrosion tests has been given by D. K. Crampton and N. W. Mitchell, "Alternate-Immersion and Water-Line Tests," Symposium on Corrosion Testing Procedures, p. 74, Chicago Regional Meeting, Am. Soc. Testing Mats. (1937). (Symposium issued as separate publication.)

In each container 1800 ml. of a distilled water solution containing 57 g. of U.S.P. sodium chloride and 3 g. of hydrogen peroxide (as H_2O_2) per liter of solution are used. Merck's C.P. 30 per cent hydrogen peroxide is generally employed, since it has been found that the stabilizers used in this material do not affect the corrosion rate. The stabilizers (such as tin salts) used in some other grades of peroxide have been found to be unsatisfactory.

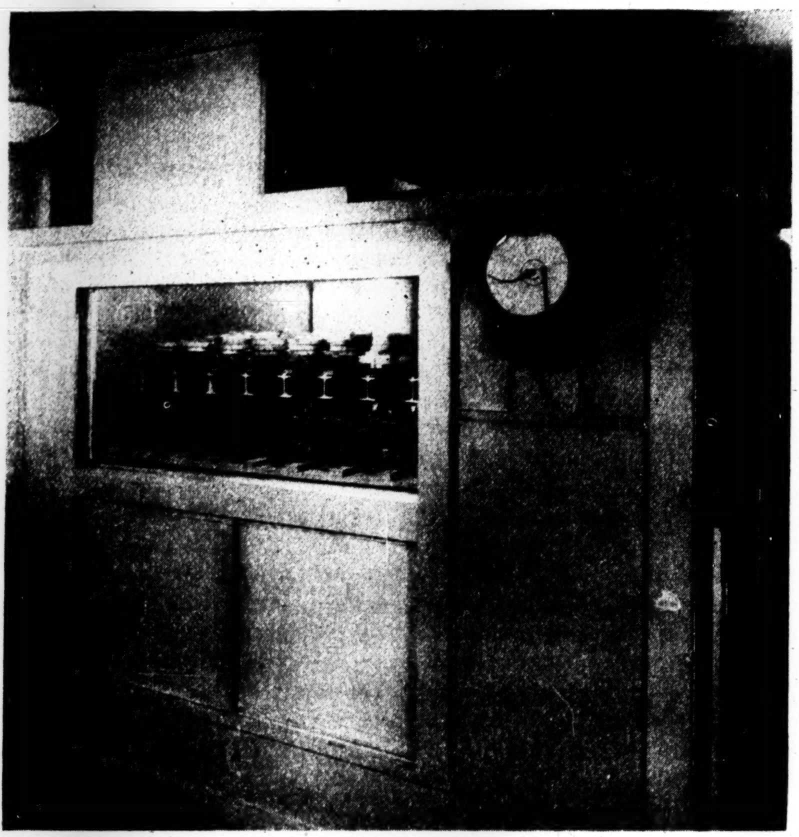


FIG. 1.—Alternate Immersion Testing Apparatus Enclosed in Insulated Cabinet.
The top doors are removed so that the solution vessels and stressed specimens can be seen.

Each shelf of the apparatus has space for 32 glass containers. Generally, standard A.S.T.M.[3] machined sheet tension specimens 9 in. long are used. Two specimens are exposed in each container. The apparatus with the outer cabinet removed is shown in Fig. 2.

The specimens are supported by aluminum alloy supports faced with glass rods. The supports are coated with a heat-reactive phenolic coating. Thus, the specimens contact only the glass rods and are, therefore, insulated from each other and from the supporting fixture. The apparatus is so designed that one specimen in each container can be stressed

---

[3] Standard Methods of Tension Testing of Metallic Materials (E 8 - 42), 1942 Book of A.S.T.M. Standards, Part I, p. 899.

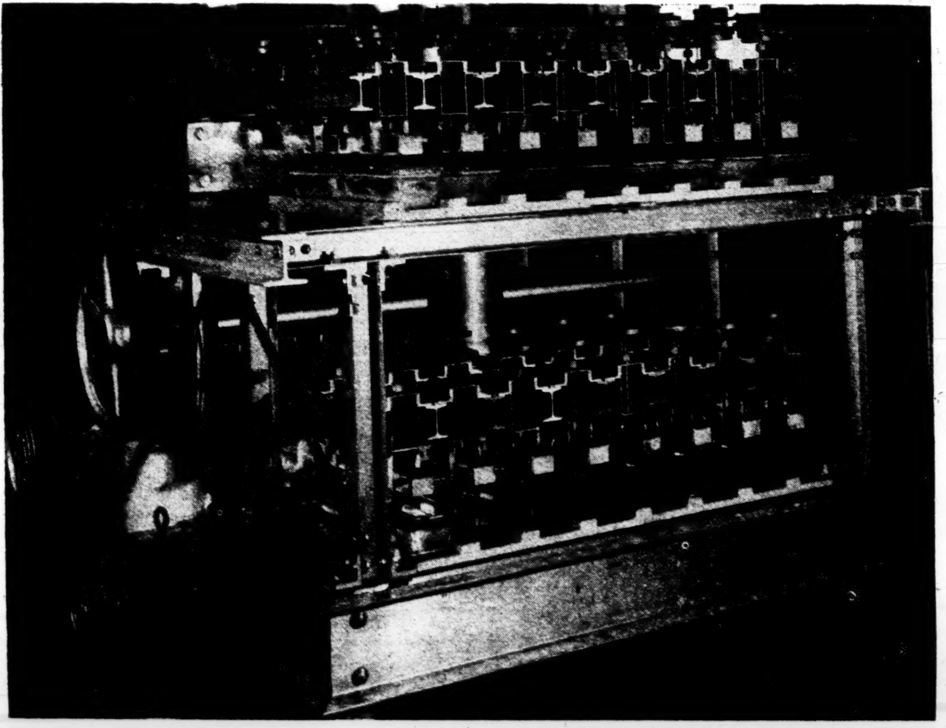


FIG. 2.—Alternate Immersion Testing Apparatus with Outer Cabinet Removed.

One of each pair of specimens in the fixtures above the top shelf is stressed as a simple beam by direct loading with lead weights. The specimens in the fixtures above the bottom shelf are not stressed.

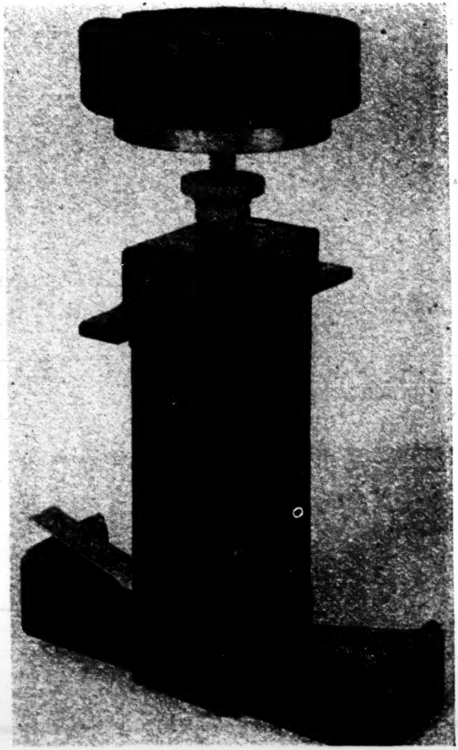


FIG. 3.—One Specimen Support Illustrating Method of Mounting One Stressed Specimen.

Usually, in addition to the stressed specimen, one unstressed specimen is also exposed on the same supporting fixture.

as a simple beam by a direct load applied at the third points by means of a glass-rod-faced aluminum alloy bridge. This bridge is also coated with a heat-reactive phenolic coating. Thus, most of the gage length of a loaded specimen is stressed nearly uniformly.

The shelves in the apparatus are designed so that they can be alternately raised and lowered for definite periods of time. This motion is controlled by a General Electric controller timing device. The cycle can be varied at will. However, with the cycle generally used, the shelves are rapidly raised and held in the raised position for $1\frac{1}{2}$ min., thus immersing the specimens in the solution. Then they are lowered rapidly and held in the lowered position for $1\frac{1}{2}$ min., thus withdrawing the vessels of solution from the specimens and exposing the specimens to the air.

By means of electric heaters, a circulating fan, and a thermoregulator, the temperature within the cabinet is maintained at some constant value, normally 30 ± 1 C. Other temperatures may be used if desired. The cabinet is equipped with an automatic temperature recorder (see Fig. 1) so that accidental variations in temperature will be recorded.

The loads used in stressing the specimens are so calculated that a stress equal to some factor times the yield strength is applied to the outer fibers of the specimen. In most cases, a stress equal to 75 per cent of the yield strength is used for the stressed specimens. The loads are applied by lead weights as shown in Figs. 2 and 3.

This apparatus, in which the containers are raised and lowered, providing the alternate immersion feature, has proved much more satisfactory than earlier models in which the specimens themselves were alternately raised and lowered into the solution.

Method of Conducting the Tests:

In conducting the tests, if stressed specimens are to be exposed, the average tensile strength, yield strength, and elongation of from two to five specimens cut from the same lot of material as that which it is desired to test are first determined. The thickness and width of the specimens to be used for corrosion testing are measured prior to exposure. From the average value of the yield strength, the load required (in pounds) to stress the specimens to the desired value (say 75 per cent of the yield strength) is calculated. Then one unstressed tension specimen and one specimen to be stressed are placed in the fixture above each container. The desired load of lead weights (in addition to the tare weight of the loading device) is loaded on the fixture above each specimen which is to be stressed, the solution is run into the glass vessels, and the alternate immersion cycle is started. Generally, two unstressed specimens and two stressed specimens from each lot of material are tested.

For No. 14-gage (0.064-in. thick) specimens, the period of exposure is 48 hr. The solution is changed at the end of each 24-hr. period of exposure.

At the conclusion of the exposure period, the specimens are removed, rinsed in cold tap water, and scraped with a piece of aluminum to remove salt and loosely adhering corrosion product. They are then rinsed again and immersed in concentrated (70 per cent) nitric acid for several minutes to remove the remaining corrosion product. This solution does not attack the specimens appreciably. After this they are rinsed, dipped in 1.0 per cent ammonium hydroxide solution to neutralize residual acidity, rinsed again, and wiped dry with cheesecloth. They are then ready for mechanical testing.

The tensile strength and elongation of the corroded specimens are measured and the percentage changes in these properties are calculated from these values and the values obtained on the original, uncorroded specimens from the same lot of material. The yield strength of the corroded specimens is not usually determined, since it has not proved to be of value in interpreting the test results.

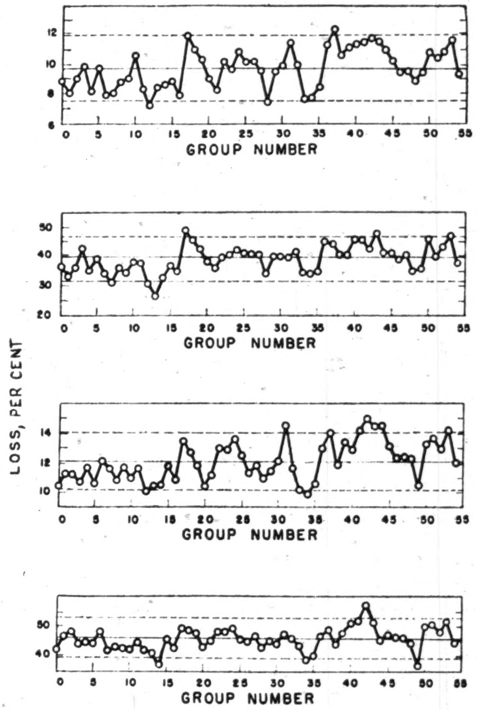


FIG. 4.—Control Charts for Losses in Tensile Strength and Elongation on Unstressed and Stressed Specimens of 17S-T Standards Exposed to the Alternate Immersion Test (3σ limits).

Top curve—Loss in tensile strength—unstressed.
Second curve—Loss in elongation—unstressed.
Third curve—Loss in tensile strength—stressed.
Bottom curve—Loss in elongation—stressed.

In each test run, two unstressed specimens and two stressed specimens from one lot of aluminum-copper alloy of known behavior are included. These specimens serve as "internal standards" to indicate whether there is anything unusual about the test conditions. In the course of time a large background of information is built up on the behavior of these "standard" specimens, since one lot of standard material will provide specimens for hundreds of tests.

Results of Corrosion Tests on Internal Standards:

During the period from October, 1938, to September, 1940, a total of 220 pairs of stressed and unstressed specimens from one lot of commercial 17S-T[4] sheet were tested as internal standards along with other routine corrosion samples. The data from these specimens are shown as control charts in Fig. 4. These charts and the calculations for the 3 σ limits were obtained using the methods recommended in the A.S.T.M. Manual on Presentation of Data, April, 1943. Averages of subgroups of four determinations each were used for each of the 55 points in each chart. The four determinations which were averaged to obtain each point were based on four successive test periods. Each of these four determinations consisted of averages from duplicate specimens.

The average loss in tensile strength for unstressed specimens was 9.7 per cent and for stressed specimens was 12.2 per cent, with average standard deviations (within subgroups) of 1.2 and 1.1 per cent, respectively. The average loss in elongation was 39.2 per cent for unstressed specimens and 45.8 per cent for stressed specimens, with average standard deviations (within subgroups) of 4.6 and 3.7 per cent, respectively.

Three points for loss of tensile strength for the unstressed specimens and seven points for stressed specimens fell outside the 3 σ limits. Five points for loss in elongation for unstressed specimens and four points for stressed specimens fell outside the 3 σ limits. Thus, the test cannot be considered to have been completely under statistical control. A number of factors might have been responsible for this lack of control, and some of these factors were investigated in special tests.

---

[4] The nominal compositions for this alloy and for others mentioned subsequently are given in Table I.

TABLE I.—NOMINAL COMPOSITION OF ALUMINUM-BASE ALLOYS MENTIONED IN TEXT.

Alloy	Alloying Elements, per cent (Aluminum and Normal Impurities Constitute Remainder)		
	Copper	Manganese	Magnesium
17S	4.0	0.5	0.5
24S	4.5	0.6	1.5

Tests on Laboratory Heat-Treated Material:

Some of the variations in the preceding series of tests might have been the result of variations in resistance to corrosion within the lot of commercially prepared 17S-T standard sheet. A special test was conducted, therefore, with sheet from one plant lot of 24S (material similar to 17S in resistance to corrosion) to study this point.

TABLE II.—RESULTS OF ALTERNATE IMMERSION TESTS ON ALUMINUM-COPPER ALLOY SPECIMENS.

	17S-T Standards		24S-T Laboratory		24S-T Standards	
	Tensile Strength	Elongation	Tensile Strength	Elongation	Tensile Strength	Elongation
Average property	64 564 psi.	20.87% in 2 in.	69 609 psi.	19.3% in 2 in.	68 820 psi.	21.2% in 2 in.
Average loss, per cent:						
Unstressed	9.7	39.2	14.6	52.4	11.7	52.1
Stressed	12.2	45.8	....	....	17.0	61.6
Over-all coefficient of variation of loss, per cent:[a]						
Unstressed	18.8	16.2	18.3	13.2	23.1	4.7
Stressed	14.4	11.5	....	....	12.5	7.6

[a] There were 220 stressed and 220 unstressed determinations of loss of the 17S-T standards, each based on two specimens.

There were 80 determinations of loss of the 24S-T laboratory material. Since these were not in duplicate, the coefficient found was divided by the square root of two to make them comparable with the standards.

There were only 16 stressed and 16 unstressed determinations of loss of the 24S-T standards, each based on two specimens.

TABLE III.—TESTS ON LABORATORY HEAT TREATED 24S-T.

Average Property Losses by Sheets and Groups of Four Sheets Quenched Together.

Sheets	Group No. 1	Group No. 2	Group No. 3	Group No. 4	Group No. 5	Average
LOSS IN TENSILE STRENGTH, PSI.						
No. 1	9 720	11 420	9 650	10 452.5	9 265	
No. 2	8 025	10 227.5	11 092.5	11 415	8 970	
No. 3	9 497.5	11 102.5	9 200	9 780	11 432.5	
No. 4	11 480	10 800	9 940	10 235	8 832.5	
Avg.	9 931	10 888	9 971	10 471	9 625	10 177
LOSS IN ELONGATION, PER CENT IN 2 IN.						
No. 1	10.75	10.875	9.625	9.875	9.50	
No. 2	10.50	10.25	11.625	11.125	9.00	
No. 3	10.125	10.125	10.625	9.625	10.625	
No. 4	10.375	8.75	9.25	10.00	9.375	
Avg.	10.44	10.00	10.28	10.16	9.62	10.10

The properties and property losses of this material which was heat treated and quenched in the laboratory are given in Table II for comparison with the properties and losses of the 17S-T standards used for the control charts. Also in

Table II are the properties of plant lot standards of 24S-T used in tests on the effect of thickness and quench to be discussed below.

TABLE IV.—TESTS ON LABORATORY HEAT TREATED 24S-T AVERAGE PROPERTY LOSSES BY PERIODS.

Period	Loss in Tensile Strength, psi.	Loss in Yield Strength, psi.	Loss in Elongation in 2 in., per cent
No. 1	10 240	3 040	10.3
No. 2	9 190	3 045	9.9
No. 3	9 185	2 945	9.6
No. 4	11 505	3 615	10.6

TABLE V.—EFFECT OF VARIATIONS IN CONCENTRATIONS OF SODIUM CHLORIDE AND HYDROGEN PEROXIDE.

Hydrogen Peroxide, g. per liter	Loss in Mechanical Properties Caused by Corrosion, per cent															
	Tensile Strength		Elongation		Tensile Strength		Elongation		Tensile Strength		Elongation		Tensile Strength		Elongation	
	U	S	U	S	U	S	U	S	U	S	U	S	U	S	U	S
	0.1 *N* NaCl				1.0 *N* NaCl				2.0 *N* NaCl				3.0 *N* NaCl			
0	2.9	2.0	11.1	7.2	2.4	1.7	15.9	11.1	2.7	1.2	23.1	12.0	4.3	4.2	24.0	26.4
1	5.6	6.5	23.1	28.8	10.3	11.3	32.7	40.9	5.8	9.7	31.3	47.1	7.1	9.5	35.1	38.5
3	9.6	10.3	30.3	37.5	12.2	13.0	38.5	42.3	13.7	15.9	47.1	51.9	13.0	16.6	42.3	51.9
5	12.3	12.7	39.9	38.5	13.8	15.7	42.3	40.9	15.4	17.5	43.3	49.5	15.1	18.6	42.3	51.9
Avg.	7.6	7.9	26.1	28.0	9.7	10.4	32.3	33.8	9.4	10.7	36.2	40.1	9.9	12.2	35.9	42.1

Normality of Sodium Chloride	0 g. per 1 liter H_2O_2				1 g. per 1 liter H_2O_2				3 g. per 1 liter H_2O_2				5 g. per 1 liter H_2O_2			
0.1	2.9	2.0	11.1	7.2	5.6	6.5	23.1	28.8	9.6	10.3	30.3	37.5	12.3	12.7	39.9	38.5
1.0	2.4	1.7	15.9	11.1	10.3	11.3	32.7	40.9	12.2	13.0	38.5	42.3	13.8	15.7	42.3	40.9
2.0	2.7	1.2	23.1	12.0	5.8	9.7	31.3	47.1	13.7	15.9	47.1	51.9	15.4	17.5	43.3	49.5
3.0	4.3	4.2	24.0	26.4	7.1	9.5	35.1	38.5	13.0	16.6	42.3	51.9	15.1	18.6	42.3	51.9
Avg.	3.1	2.3	18.5	14.2	7.2	9.3	30.5	38.8	12.1	14.0	39.6	45.9	14.2	16.1	42.0	45.2

NOTES.—Tests made on tension specimens machined (cross-grain) from 0.064-in. thick commercial 17S-T sheet.

Specimens were etched to produce a uniform surface and exposed for 24 hr. by alternate immersion in the above combinations of sodium chloride-hydrogen peroxide solutions at 30 C.

The results are the average of two specimens.

One unstressed (U) and one specimen stressed to 75 per cent yield strength (S) were exposed per dish (1800 ml. solution).

Twenty sheets from one plant lot of 24S-T were used for these tests. Each sheet was 0.064 by 10 by 10 in. in size. They were heat treated and quenched in iced brine in sets of four in the laboratory. Twelve cross-grain tension specimens were machined from each sheet, and the specimens were numbered so that their original positions in the sheet could be established. From each sheet, specimens Nos. 1, 4, 7, and 10 were tested in the uncorroded condition; specimens Nos. 2, 5, 8, and 11 were exposed in the unstressed condition. They were tested in various positions in the alternate immersion apparatus, and in four successive periods. The changes in tensile properties resulting from the exposure were calculated.

In Table III are given the losses in properties according to sheets and groups of four sheets heat treated and quenched together. The differences in tensile strength and elongation among the sets and sheets were not found to be significant by an analysis of variance based on 95 per cent probabilities.

In Table IV are given the average losses in properties by the four periods. For tensile strength, the variation between periods was found to be significant by a similar analysis of variance. This variation between periods verifies the

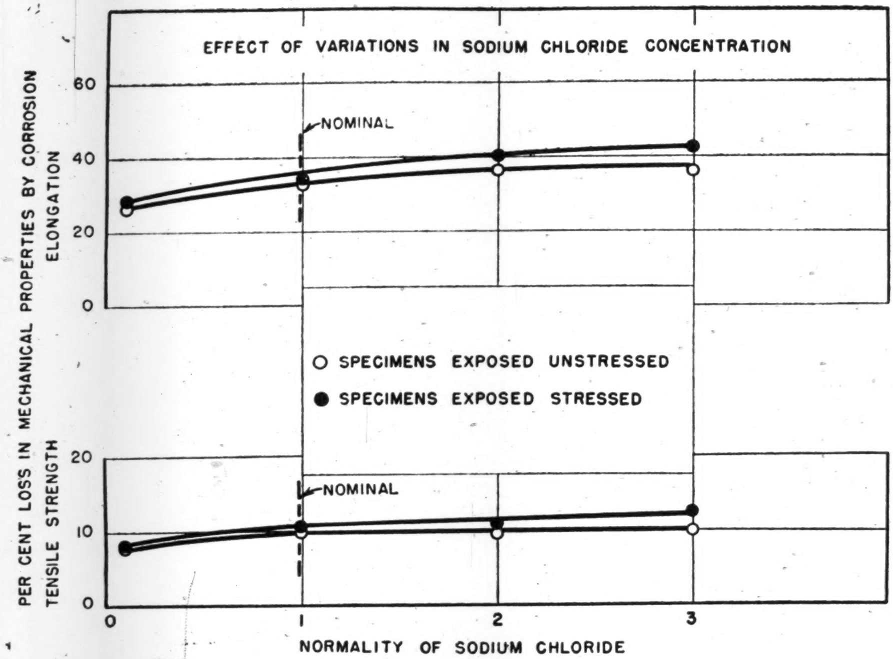


FIG. 5.—Effect of Variation in Concentration of Sodium Chloride on Rate of Attack of 17S-T Standards in the Alternate Immersion Test.

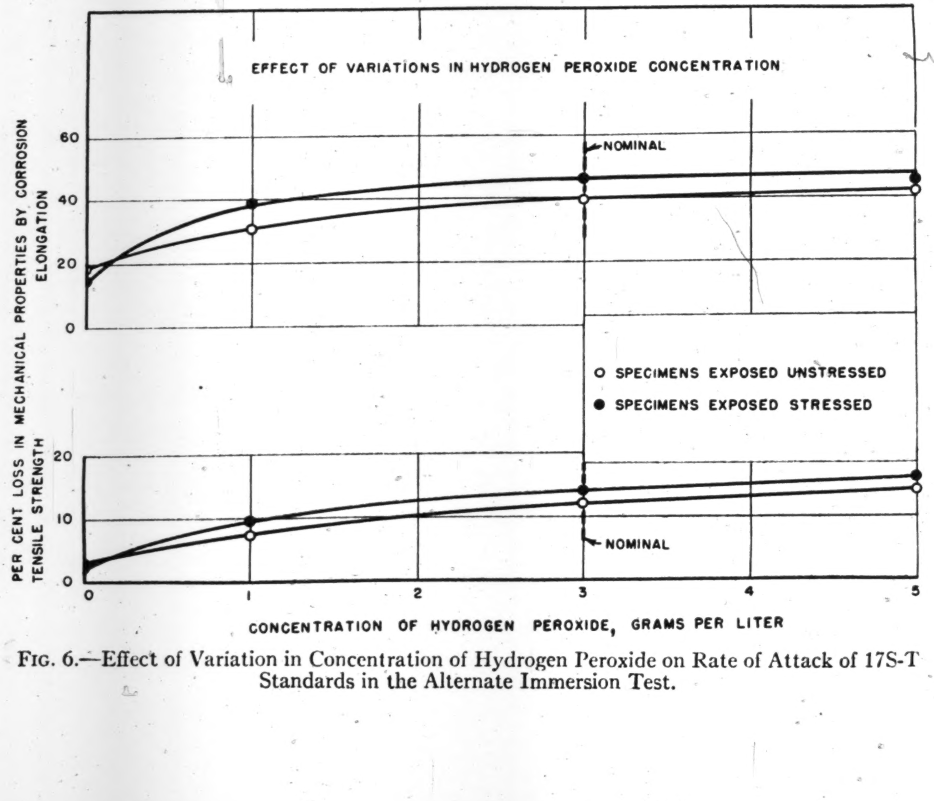


FIG. 6.—Effect of Variation in Concentration of Hydrogen Peroxide on Rate of Attack of 17S-T Standards in the Alternate Immersion Test.

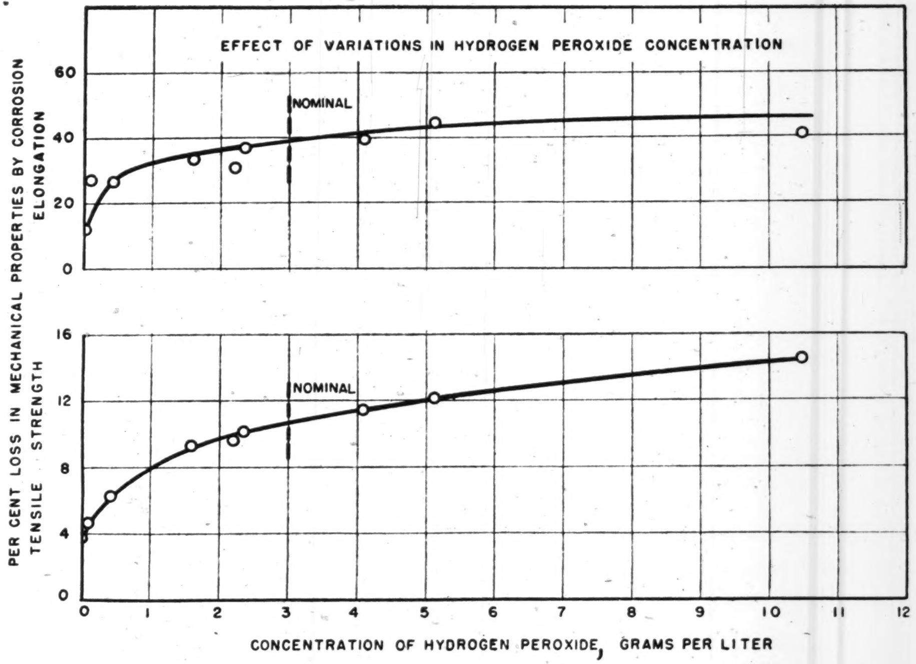


FIG. 7.—Effect of Variation in Concentration of Hydrogen Peroxide on Rate of Attack of 17S-T Standards in the Alternate Immersion Test. These results were obtained independently from those of Fig. 6.

TABLE VI.—EFFECT OF VARIATIONS IN CONCENTRATION OF HYDROGEN PEROXIDE ON THE CORROSIVENESS OF A 1 N SODIUM CHLORIDE SOLUTION.

Hydrogen Peroxide Concentration in Solution, g. per liter			Loss by Corrosion, per cent			
			Tensile Strength		Elongation	
Original	After 18 hr.	After 24 hr.	Unstressed	Stressed	Unstressed	Stressed
0	0	0	3.4	4.2	12.7	11.3
0.09	0.02	0.01	4.3	5.0	29.2	24.5
0.43	0.11	0.05	5.4	7.2	23.1	30.2
1.59	0.30	0.15	8.4	10.1	29.2	37.2
2.20	0.35	0.18	7.5	11.7	22.2	38.7
2.34	0.40	0.18	8.5	11.9	31.6	42.0
4.08	0.58	0.27	10.0	13.0	34.9	43.4
5.12	0.72	0.34	13.4	11.0	43.4	45.8
10.48	1.84	1.00	13.7	15.5	35.4	46.7

NOTES.—Tests made on tension specimens machined (cross-grain) from 0.064 in. thick commercial 17S-T sheet.

Specimens were etched to produce a uniform surface and exposed for 24 hr. by alternate immersion in 1 N sodium chloride solution (at 30 C.) containing varying amounts of hydrogen peroxide as indicated.

The results are the average of two specimens.

One unstressed and one specimen stressed to 75 per cent yield strength were exposed per dish (1800 ml. solution).

day to day differences, some of which were outside the limits in the control charts.

The over-all coefficients of variation for the unstressed 17S-T standards data shown in the control chart were 18.8 per cent for tensile strength, and 16.2 per cent for elongation. Since these were not significantly higher than the respective 18.3 per cent and 13.2 per cent for the special experiment in which precautions were taken to minimize differences in heat treating and quenching, it may be concluded that such differences in the standard material were small and are probably not the cause of the points falling out of the control limits in Fig. 4.

Effect of Variation in Concentration of Solution:

Two special series of tests were run to determine the effect of changes in the concentration of the solution. For these tests, tension specimens were machined from one sheet (0.064 in. thick) of 17S-T standard material. In one series, the sodium chloride concentrations and the hydrogen peroxide concentrations were varied independently. In the other series with constant sodium chloride concentration, the hydrogen peroxide content was varied. The average results of tests performed on duplicate specimens are summarized in Figs. 5, 6, and 7 and given in detail in Tables V and VI. These results indicate that increasing either the sodium chloride concentration or the hydrogen peroxide concentration tends to increase the rate of attack. However, increases in sodium chloride concentration from 0.1N to 3N have less effect than changing the hydrogen peroxide concentration from 1 g. per liter to 5 g. per liter.

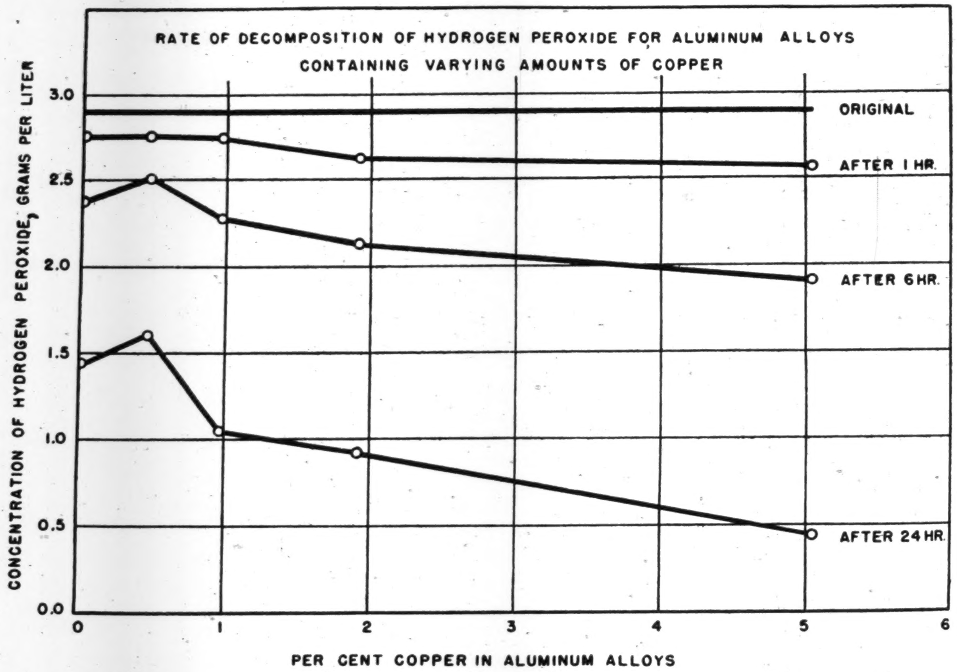


FIG. 8.—Effect of Composition of Aluminum Alloy Specimens on Rate of Decomposition of Hydrogen Peroxide during Alternate Immersion Testing.

Decomposition of Hydrogen Peroxide:

During the corrosion test the sodium chloride in the solution is not consumed. However, the hydrogen peroxide is decomposed, probably by two mechanisms. Some of the hydrogen peroxide is consumed by reaction with hydrogen deposited on cathodic areas of the specimens as a result of the corrosion reaction. Also, some peroxide is probably decomposed catalytically, either by the alloying agents or by impurities in the specimens. This is probably particularly true in the case of specimens of aluminum-copper alloys, since copper is known to catalyze the decomposition of hydrogen peroxide.

The concentrations of hydrogen peroxide in the solutions at the beginning and at two periods during the test are shown in Table VI. It is evident that by the end of 24 hr. most of the peroxide is used up. This is the reason the solution is renewed at the end of each 24-hr. test period.

Some idea of the relative magnitudes of the two factors influencing the decomposition of the peroxide may be obtained from Fig. 8. Here the initial peroxide content and the contents after three periods of exposure are given for solutions contacting aluminum alloy specimens of varying copper contents. At the end of one day, the peroxide concentration remaining in the solution used for aluminum alloy specimens containing 5 per cent copper was only about one third that in a solution used in contact with specimens containing 0.01 per cent copper.

TABLE VII.—EFFECT OF SUNLIGHT ON CORROSIVENESS AND STABILITY OF STANDARD SODIUM CHLORIDE-HYDROGEN PEROXIDE SOLUTION.[a]

Exposed	Alloy	Loss by Corrosion, per cent[c]		Hydrogen Peroxide in Corrosive Solution, g. per liter			
				Unused Solution		Solution Removed from Corrosion Test	
		Tensile Strength	Elongation	Original	After 24 hr.	After 6 hr.	After 24 hr.
Total darkness	17S-T	9.3	33.3	3.3	2.9	0.7	0.0023
Sunlight[b]	17S-T	8.7	35.7	3.3	3.0	0.7	0.0025
Total darkness	24S-T	10.9	49.2	3.3	2.9	0.8	0.0028
Sunlight[b]	24S-T	9.5	45.2	3.3	3.0	0.8	0.0025

[a] Freshly prepared solution used containing 57 g. sodium chloride and 3.3 g. hydrogen peroxide per liter.

[b] Dishes of specimens were exposed indoors on bench 4 ft. from large window on south end of laboratory and on a clear, sunny day in June.

[c] Average of tests made on three 0.064-in. thick (cross-grain) tension specimens that had been totally immersed for 24 hr. in 1800 ml. of above corrosive solution.

TABLE VIII.—EFFECT OF RATIO OF VOLUME OF SOLUTION TO SURFACE AREA EXPOSED ON THE LOSSES IN MECHANICAL PROPERTIES OF 17S-T ALLOY SHEET.

Specimens Per Dish	Volume of Solution, ml.	Solution-Area Ratio, ml. per sq. cm.	Loss by Corrosion, per cent	
			Tensile Strength	Elongation
1	1800	21.1	12.5	36.4
	1600	18.8	13.0	43.4
	1400	16.4	12.4	38.7
2	1800	10.6	12.8	42.0
	1600	9.4	12.2	39.9
	1400	8.2	11.7	41.1
3	1800	7.0	11.0	39.9
	1600	6.3	10.3	35.2
	1400	5.5	10.9	40.6

NOTES.—Tests made on tension specimens machined (cross-grain) from 0.064-in. thick commercial 17S-T sheet.

Specimens were etched to produce a uniform surface. Duplicate sets of specimens were exposed for 24 hr. by alternate immersion in a solution containing 57 g. sodium chloride and 3 g. hydrogen peroxide per liter at 30 C.

These alternate immersion tests are generally conducted inside a closed cabinet and, therefore, in practically total darkness. However, a few tests were made to investigate the effect of sunlight on the rate of decomposition of hydrogen peroxide in the test solutions. These results are summarized in Table VII. Evidently diffused sunlight is not a factor of importance in influencing the rate of decomposition of hydrogen peroxide in these test solutions.

Effect of Change in Volume of Solution per Unit Area:

In a special series of tests the effect of variation in volume of solution per unit area of exposed surface of the specimens was investigated. The data obtained are summarized in Table VIII and Fig. 13. These data show that losses in mechanical properties are slightly higher in cases where there is a large solution—surface area ratio. However, the effect is not large, especially when the volume of solution is greater than about 8.2 ml. per sq. cm. of surface area.

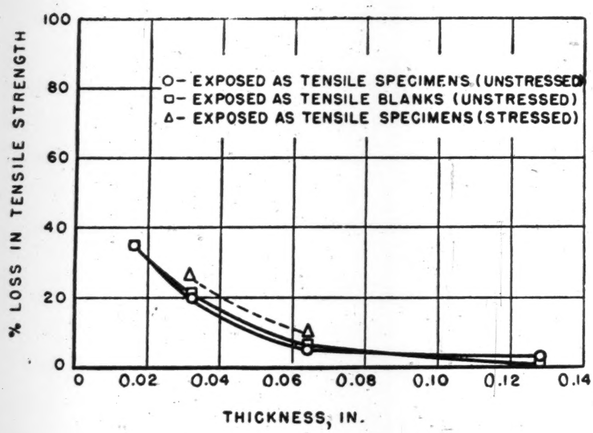


FIG. 9.—Effect of Change in Thickness on Change in Tensile Strength of 24S-T Specimens Quenched in Iced Brine at 0 F. and Exposed to the Alternate Immersion Test.

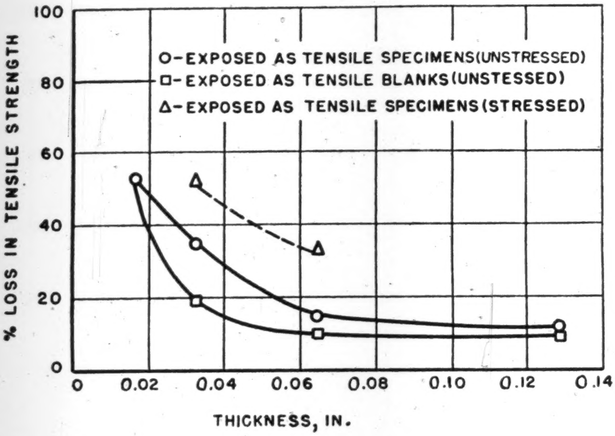


FIG. 10.—Effect of Change in Thickness on Change in Tensile Strength of 24S-T Specimens Quenched in Warm Water at 160 F. and Exposed to the Alternate Immersion Test.

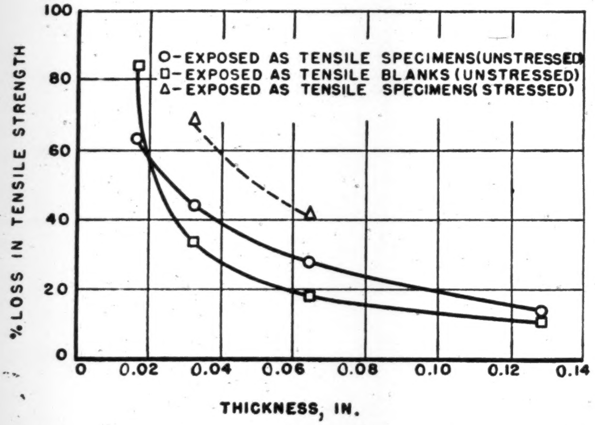


FIG. 11.—Effect of Change in Thickness on Change in Tensile Strength of 24S-T Specimens Quenched in Boiling Water at 212 F. and Exposed to the Alternate Immersion Test.

Effect of Change in Thickness of Specimens:

The effect of change in specimen thickness and also in rate of quench from the heat-treating temperature was investigated. A sheet of four different thicknesses was rolled from one cast of 24S-T. The thicknesses were 0.016, 0.032, 0.064, and 0.128 in. All of the sheet was heat treated under similar conditions, but some of each gage was quenched in iced brine at 0 F., some in hot water at 160 F., and some in boiling water at 212 F. From each of the twelve lots of material thus obtained, six machined tension specimens and two tension blanks were prepared. The tension blanks were strips of metal $\frac{13}{16}$ in. wide by 9 in. long.

Two of the machined specimens were used to determine the initial uncorroded properties of each lot, two were exposed to the sodium chloride-hydrogen peroxide alternate immersion test unstressed, and two were exposed stressed to 75 per cent of their yield strength.[5] The unmachined tension blanks were also exposed to the alternate immersion test for 24 hr. They were then machined into tension specimens. The mechanical properties of all the exposed specimens were determined, and the changes in properties as a result of the exposure were calculated. The results are illustrated in Figs. 9, 10, and 11. The losses in tensile strength decrease approximately as the thickness of the specimens is increased from 0.016 in. to 0.064 in. For change in thickness from 0.064 in. to 0.128 in. the loss does not decrease in proportion to the increased thickness. Changes in strength for specimens machined before exposure are similar to, though generally slightly higher than, those from specimens machined after exposure. The stressed specimens lose more than the comparable unstressed specimens, especially in the case of material which was quenched slowly. As would be expected, changes in tensile strength are higher for specimens which have been slowly quenched from the heat-treating temperature than for those which have been quenched rapidly.

In addition, similar specimens were exposed to the outdoor atmosphere at the seacoast (Point Judith, R. I.). Some of the results are summarized in Fig. 12. It will be noted that losses in tensile strength for specimens quenched rapidly in iced brine are about the same after exposure to the alternate immersion test for 24 hr. as after 6 months exposure on the seacoast. It should be emphasized, however, that a close correlation of this kind was not obtained between losses in strength for the more slowly quenched specimens exposed in the two tests. This confirms the statement made earlier that the alternate immersion test cannot be used as an "accelerated corrosion test" to evaluate miscellaneous materials in terms of service conditions.

Effect of Method of Surface Preparation:

A special series of tests was conducted to determine whether there was any difference between two methods of surface preparation used in preparing specimens for the alternate immersion test. Thirty-six tension specimens (six from each of six different sheets) from one lot of standard 17S-T were cleaned by vapor degreasing. Thirty-six similar specimens from the same sheets were cleaned by etching for 1 min. in a solution containing 50 ml. concentrated (70 per cent) nitric acid and 5 ml. concentrated (48 per cent) hydrofluoric acid per liter at 95 C. Eighteen specimens cleaned by each method were exposed unstressed

---

[5] This could be accomplished only in the case of specimens 0.032 in. and 0.064 in. thick, since the fixtures are not designed to handle thinner or thicker specimens.

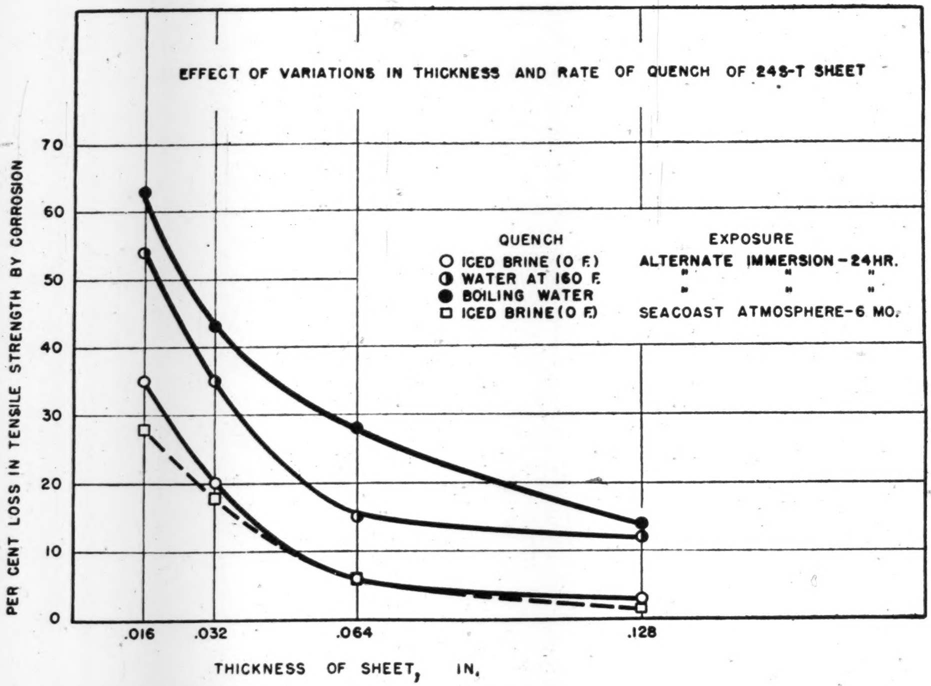


FIG. 12.—Effect of Change in Thickness and In Rate of Quench on the Tensile Strength of 24S-T Specimens Exposed to the Alternate Immersion Test.

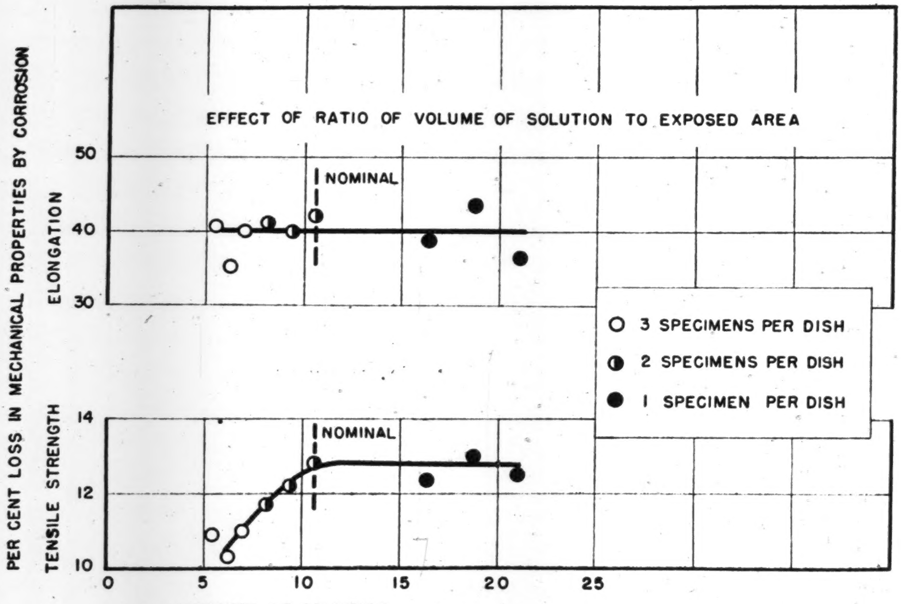


FIG. 13.—Effect of Change in Volume of Solution per Unit Surface Area of 17S-T Specimens Exposed in the Alternate Immersion Test.

to the alternate immersion test for 24 hr. A similar number of specimens were exposed stressed to 75 per cent of their yield strength. The results, given in Table IX, indicate that losses in tensile strength for both unstressed and stressed specimens cleaned by etching are higher and more uniform than are those for specimens cleaned by vapor degreasing.

Tests of significance[6] indicated that the difference in losses for specimens cleaned by the two methods was statistically significant as was also the difference in their standard deviations.

TABLE IX.—EFFECT OF SURFACE TREATMENT.

Sheet	Average Loss in Tensile Strength, per cent			
	Vapor Degreased		Etched	
	Unstressed	Stressed	Unstressed	Stressed
No. 1	6.2	9.1	8.8	10.4
No. 2	7.3	8.4	9.0	11.2
No. 3	6.7	10.2	10.6	11.4
No. 4	6.1	7.9	8.5	10.1
No. 5	6.7	7.3	8.0	10.1
No. 6	7.0	7.8	8.5	10.7
Avg.	6.7	8.5	8.9	10.7
Standard deviation[a]	1.21	0.95	0.89	0.53

NOTES.—Machined tension specimens 0.064-in. thick of 17S-T standards were exposed for 24 hr. to the alternate immersion test.

Average of three specimens from the same sheet.

Stressed to 75 per cent of the yield strength.

[a] Standard deviations of all 18 specimens around their six averages.

Effect of Duration of Exposure:

Tests were made to determine the effect of change in the duration to the alternate immersion test. Machined tension specimens and also unmachined tension blanks from one sheet of 17S-T standards were exposed, both unstressed and stressed to 75 per cent of their yield strength, in the alternate immersion test for five periods of exposure. Duplicate specimens were exposed in all cases. The solutions were changed at the end of each 24 hr., in the case of exposures of 48 hr. or over. The results are given in Table X.

TABLE X.—EFFECT OF CHANGE IN THE DURATION OF EXPOSURE TO THE ALTERNATE IMMERSION TEST.

Period of Exposure, hr.	Loss in Tensile Strength, per cent			Loss in Elongation, per cent		
	Unstressed	Stressed	Average	Unstressed	Stressed	Average
MACHINED TENSION SPECIMENS						
12	5	7	6.0	18	28	23.0
24	5	8	6.5	19	35	27.0
48	8	11	9.5	30	41	35.5
72	11	14	12.5	43	52	47.5
96	16	14	15.0	53	52	52.5
UNMACHINED TENSION BLANKS						
12	4	6	5.0	17	29	23.0
24	6	6	6.0	26	29	27.5
48	9	11	10.0	41	39	40.0
72	9	14	11.5	37	48	42.5
96	11	13	12.0	48	50	49.0

NOTES.—These results are averages from duplicate specimens of 17S-T, 0.064-in. thick.

The solution was changed at the end of each 24-hr. period of exposure.

These results indicate that the changes in tensile strength increase nearly linearly as the time of exposure is increased. It is known that this relationship would not hold if the solutions had not been changed periodically or if the tests had been continued over still longer periods of time.

In contrast to this, the rate of increase in elongation losses fell off with increasing duration of exposure.

---

[6] R. A. Fisher, "Statistical Methods for Research Workers," Sixth Edition, Oliver and Boyd, p. 230.

BASIC REQUIREMENTS IN THE STANDARDIZATION OF THE SALT SPRAY CORROSION TEST

BY LEO J. WALDRON[1]

SYNOPSIS

The salt spray has assumed unusual importance within the past few years in the testing of materials, principally certain articles intended for use either on shipboard or at shore installations, or which must withstand storage under maritime exposures. The loss of materials and supplies under these conditions has been sufficiently great to warrant the incorporation of salt spray test requirements into many purchase specifications. Increased use of the test has made it advisable to revise existing requirements so that more care can be exercised over some of the details of the testing procedures involved. Closer control of the variables is necessary if comparable and reproducible results are to be obtained by various testing laboratories.

The basic requirements for operating and controlling the salt spray test are discussed in the light of recent experience with the method. The effect of such factors as temperature, concentration and purity of salt and type of water used for the solution, importance of proper air for atomization, and requirements for efficient atomization of the solution are discussed as the important variables.

Among various laboratory corrosion tests widely used over a period of years in this country is the salt spray test. Its use within the past few years has increased greatly and interest in the test is now at the highest pitch since its introduction 30 yr. ago. It seems appropriate at this time to discuss some of the basic requirements which should be met in a standard testing procedure.

The name, "salt spray test," is a misnomer in that the specimen is exposed to a "fog" or "mist" rather than to a "spray." However, a recent proposal to change the name of the test to "salt fog test" met with strong objections, mainly because it was felt that considerable confusion might result from the change. It was suggested that it be known hereafter as the "salt spray (fog) test."

The first published description of this test, given by Capp (**1**)[2] in 1914, appeared in the *Proceedings* of this Society. Being interested in the service behavior of certain metallic protective coatings intended for use under seacoast conditions, Capp observed their response to exposure in a mist formed by atomizing a saline solution. This has constituted the basic feature of all salt spray tests.

Shortly thereafter, the National Bureau of Standards became interested in the possibilities of the test and continuous use has been made of it since then (1919) (**3**).

The American Society for Testing Materials has had much to do with this particular test, specifically with regard to development of testing procedure. Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys has been actively engaged for a long time in intensive studies of the salt spray test in connection with its investigations (9). In addition, the possible usefulness of various other chemicals was considered in the committee's original spray test program. This work culminated in the publication in 1939 of a standard procedure covering the detail requirements of operation of the test.[3] However, increased use of the test has served to emphasize the need for modifications of these requirements (10). Committees B-8 on Electrodeposited Metallic Coatings and D-1 on Paint have also been interested in the salt spray test, particularly in its specific application to electroplated and painted metals.[4]

---

[1] Metallurgist, National Bureau of Standards, Washington, D. C.

[2] The bold face numbers in parentheses refer to the reports and papers appearing in the list of references appended to this paper, see p. 661.

As indicated by the title of this paper, it is not the author's purpose to discuss the interpretation of results or their correlation with service conditions, nor the recommended uses or limitations of the test. These have been covered by various investigators and an admirable presentation along these lines was made at the annual meeting of the A.S.T.M. in 1943 by Sample (11).

PROGRESS TOWARD STANDARDIZATION

In its early development, the salt spray test consisted merely of exposing samples within a closed box to a mist produced by atomizing a sodium chloride solution, usually with no attempt to control any of the variables. Naturally, reproducible results were hard to obtain and the test fell into disrepute in some laboratories.

The coming of the present war necessitated the sending of immense quantities of metallic materials overseas and also using various metals under new conditions, on shipboard, at shore installations, and in storage under marine exposures where the corrosion hazard, principally from salt water or air, is of controlling importance. Huge volumes of materials are unloaded in water, and gathered in and stored on beaches under the most severely corrosive conditions. Experimental work was immediately undertaken with the objective of adequately protecting these vital materials from the corrosion thus encountered. Among the suggested corrosion tests to serve as guides and checks in the development work, the salt spray appeared especially worthy of merit.

Over a year ago, the Military Planning Division of the Office of the Quartermaster General in cooperation with the National Bureau of Standards began experimenting with the salt spray test on the quality and uniformity of protective coatings on metals for the purpose of developing specifications for testing such coatings. After a great deal of preliminary work it was concluded (12) that "extremely divergent results were obtained if a definite testing procedure was not observed by different operators," but that "when all variables are controlled, a laboratory test of considerable value for certain purposes is available."

When the results of this work were made known to other government agencies and to committees of the Society, a desire was expressed for a more rigid control of the test. Revision of existing requirements was discussed early this year by subcommittees of both Committees B-3 and D-1 at the 1944 A.S.T.M. Spring Meeting (Cincinnati) and subsequently at two meetings held in Washington. At the latter meetings, a special informal committee composed of representatives of various government agencies, technical societies, and others interested in standardization of the salt spray test formulated a master proposal describing a standard method of conducting the test which could be adopted as the basis of a specification by any organization. Its aim was the standardization of those factors which hitherto have prevented either consistent or reproducible results. This proposal is now in a form suitable for consideration by those organizations concerned but is not yet available for general distribution. The task of issuing specifications or standards thus lies within the jurisdiction of the respective government departments or technical societies concerned.

---

[3] Tentative Method of Salt Spray Testing of Non-Ferrous Metals (B 117 - 41 T), 1942 Book of A.S.T.M. Standards, Part I, p. 1469.

[4] Tentative Specifications for Electrodeposited Coatings of Nickel and Chromium on Steel (A 166 - 41 T). 1942 Book of A.S.T.M. Standards, Part I, p. 1454. Emergency Method for Conducting Salt Spray Tests on Organic Protective Coatings (ES - 3), 1942 Book of A.S.T.M. Standards, Part II, p. 1020.

There is an evident desire among various government agencies to eliminate the different departmental specifications for salt spray testing and to substitute a general Federal Specification. It is likewise desirable that future existing specifications issued by this Society or related organizations be consistent with the proposed new standard.

BASIC FACTORS OF THE TEST

It is surprising that with a test which has been in use as long as has the salt spray the effects of the various factors have not been more seriously considered. Anyone who has had experience with the test will concede that considerable difficulty is involved in securing adequate data on the basic factors. Specific information obtained for a given set of conditions or materials may not always be applicable in testing other materials or under different conditions. Because the test as used today is usually arbitrary, for some specific application, we are justified (**11**) in specifying standard methods of control and operation so that the results obtained in various laboratories will be comparable and reproducible. The operating conditions might be varied to meet some particular service condition (**11**) if necessary to achieve the desired end. However, where it is used as a control check on specification requirements, its widespread use demands rigid standardization of the testing procedures.

Temperature:

Since the rate of most chemical reactions in aqueous solutions increases with increase in temperature, the importance of standardization and control of this factor has long been recognized. In 1924, Rawdon (**9**) suggested the use of 30 ± 1 C. and again in 1928 (**6**) warned against the use of the test for temperatures varying over a wide range. Since 1930 the National Bureau of Standards has conducted this test in a constant temperature room. Buzzard (**8**), in cooperative work with the Aluminum Company of America (**14**) and Naval Aircraft Factory showed that variations in temperature of the salt spray had a marked effect on the loss in physical properties of sheet duralumin and suggested that a standard temperature of 35 ± 2 C. could be maintained throughout the country without cooling equipment in the summer and with only simple heating equipment in winter. Heussner (**13**) found less effect of temperature upon the corrosion of electroplated steel panels in a salt spray test with 20 per cent NaCl solution than with $3\frac{1}{2}$ per cent sea water. Many laboratories in this country are set up to conduct the test at a temperature of 95 F. (35 C.) and it therefore appears advisable to continue its use. A temperature of $95 + 2$ or -3 F. ($35 + 1$ or $-1\frac{1}{2}$ C.) was suggested for inclusion in new specifications as a result of the deliberations of the special committee.

In spite of repeated emphasis of the importance of close temperature control, and its inclusion in specifications, returns from a recent questionnaire (10) on the operation of the salt spray test revealed that only about 50 per cent of the laboratories canvassed were using a "controlled temperature" of 95 F., while the others were using "room temperatures," which may vary over a considerable range.

Various methods are employed to maintain a constant temperature within the box. Some laboratories keep the boxes and equipment in a constant-temperature room, others use heaters located in either the walls of the box or the solution reservoir, some use a temperature-controlled water jacket around the box, and some a combination of these methods. A method based on warming the incoming air delivered to the spray nozzles and operating in a room maintained at a constant temperature has distinct advantage over the other methods. In any case, the particular control adopted should maintain a specified constant temperature in that portion of the box where samples are exposed.

Much confusion exists with regard to temperature variations within a test box when it is in operation. The temperature of the incoming air delivered to the nozzles is important since if it is much below 35 C., the large volume of air required for atomization of the solution may cause decided cooling effects. This results from two causes, the Joule-Thomson effect and the evaporation of solution. If a low pressure nozzle (10 to 15 lb.) is employed, the drop in temperature produced by expansion of the air as it leaves the nozzle orifice to approximately atmospheric pressure (Joule-Thomson effect) will amount to only a small fraction of a degree.

Greater cooling occurs if the air is not saturated with water vapor equivalent to that concentration necessary for equilibrium in the mist. A relative humidity of 84 per cent is produced by a 20 per cent solution of sodium chloride at 35 C. If the incoming air has a humidity of less than 84 per cent, equilibrium is quickly reached by evaporation of the salt solution at the nozzle and in the fog. This evaporation is accompanied by a relatively great cooling effect within the box. Undoubtedly some of the large temperature drops measured in certain boxes in the past were produced by these cooling effects.

Temperature measurements are low and give misleading results if any evaporation takes place from a bulb of the thermometer or thermocouple used. This "wet bulb" effect is appreciable and may occur when measurements are made with the box open, even in a constant-temperature room, or when the air in the box is not saturated with water vapor. Also, temperature measurements made in that portion of the box in which the fog is being produced may be misleading because of the thermal transfers accompanying atomization of the solution. The temperature within the space in the box where samples are exposed is important and should be controlled.

Salt Solution:

The salt spray test was originated as an "exaggeration of what may be expected at the seashore, and differs only in degree, not in kind, from the normal conditions under which the article is to be used" (1). For this reason, with but few exceptions, sodium chloride solutions have been principally used. For a number of years, some laboratories used actual sea water while others compounded "synthetic sea waters." However, in recent years this practice has ceased except for special cases. Sodium chloride of either high purity or commercial grade is now used. Very little information is available as to the relative effects of sea water and sodium chloride solutions, although the former is generally assumed to be the more severe since it contains impurities that may be more corrosive than sodium chloride. Heussner (13) reported that, in salt spray tests of electroplated steel, the ocean spray was more severe than 20 per cent NaCl in a test conducted at 95 F., but that at 72 F. they were nearly equal.

The concentration of the solution used for the salt spray test has varied widely. Capp initially used a saturated solution but changed to a 3 per cent solution to eliminate the tendency for salt to clog the nozzles (the NaCl concentration of sea water is approximately 3 to 4 per cent). Finn (2), in 1918, recommended the use of a 20 per cent concentration. During the 1920's, the use of a 4 per cent solution was widespread, especially by the Navy in its testing work. However, dating from 1932, the tendency has been to use 20 per cent solutions in most tests. A larger background of experience has been built upon its use than on solutions of other concentrations.

General experience has indicated no marked difference in the corrosive attack between the 20 per cent solution and those of lower concentrations. Data are available indicating (13) that the 20 per cent solution is affected less by temperature changes than are solutions of lower concentrations because its oxygen solubilities are less subject to change. One reason given for using solutions of low concentration, such as 5 per cent, is to reduce the amount of salt required. However, recent experiments at this Bureau indicate that a larger volume of the more dilute solution is aspirated and would consequently require nearly as much salt as if the more concentrated (20 per cent) solution were used.

A frequent objection to the use of the 20 per cent sodium chloride solution is the tendency of solid salt to deposit either on the specimens or around the spray nozzle and thus interfere with the test. This behavior was pointed out in 1938 by Mutchler, Buzzard, and Strausser (8), who attributed it to improper functioning of the apparatus through the use of air containing an insufficient amount of water vapor. Experience and data secured with the use of "fog-collection devices" have confirmed this explanation. No such difficulty has been experienced in the author's laboratory over a period of nearly 10 yr., even with numerous nozzles operating in several boxes. Its occurrence is now regarded as evidence that immediate adjustment of the apparatus is needed. The use of fog-collection devices (see below) along with the samples in a spray box will eliminate this difficulty as they are a sensitive indicator of changes due to either evaporation or condensation of water vapor.

Agreement has been lacking as to the purity of both the sodium chloride and water used in making up the solution to be atomized. The general use of c. p. salt, containing 99.98 per cent NaCl, would be preferable, but its use would entail an expense item of considerable magnitude if much testing work were carried out. In many laboratories high-purity, commercial grades of salt, containing at least 99.8 per cent NaCl are now used and there has been no evidence thus far to indicate marked differences in corrosive effects from its use. Distilled water is widely used in preparing the salt solutions, but its use may be impracticable if large quantities of solution must be made up each day. Since great differences may exist in the composition of natural or treated waters, the general use of these in preparing the salt solution might introduce another variable in the test. However, if the water does not contain a large amount of dissolved solids, it can be used without introducing serious complications. Hitherto, most specifications have called for a pH range of 6 to 7 for the salt solution. It is believed that the corrosion of most materials in this test will be only little affected if the solution is maintained within a narrow pH range at the neutral point.

The special committee has proposed (*a*) the use of sodium chloride containing, on the dry basis, not more than 0.1 per cent sodium iodide or more than 0.2 per cent of total impurities, (*b*) the use of distilled water or other water containing not more than 200 ppm. of total solids, and (*c*) that the pH range of the salt solution be maintained between 6.5 and 7.2 and that adjustments be made by additions of small volumes of dilute c. p. hydrochloric acid or c. p. sodium hydroxide.

Atomization:

In practically all salt spray test apparatus the mist is produced by an atomizer or nozzle. Compressed air, saturated with water vapor, is allowed to expand through a small orifice and the suction thus created draws the salt solution into the air stream in the form of very fine particles. The solution is then said to be atomized. The mist or fog carried by the air stream consists of droplets of salt solution of various sizes. Impingement of this mist on a flat surface or baffle tends to remove most of the larger-sized particles. If the air currents accompanying atomization are particularly violent or decidedly directional, a more severe corrosive action on specimens in some parts of the chamber than in others may result. The nozzle operating pressure should be held to the minimum compatible with the efficient production of the mist.

The importance of proper air for atomizing the salt solution has only recently been appreciated. It has long been recognized that the air should be free of impurities such as oil, dirt, and objectionable gases. A relative humidity of at least 90 per cent has been generally recommended. The effect of the water vapor contained in the incoming air upon the temperature has been discussed previously. However, a far more important effect of humidity is the character of the mist that settles upon the samples. This has been demonstrated recently by a number of investigators as a result of work with the "fog-collection devices" suggested by Darsey (15).

The humidity of the air in the box will be in equilibrium with the mist of salt solution shortly after atomization, in fact spraying is one of our most efficient methods of saturating air with moisture. When saturated to a point of equilibrium with the salt solution, however, the air in the box will contain only 84 per cent of the moisture necessary to establish equilibrium with pure water. The requisite amount of water vapor can come from only two sources. It is either already contained in the incoming air, or it is gained by evaporation of water from the salt solution. Even though the compressed air is saturated at 35 C. before passing through the nozzle, it will not be saturated after expanding to the atmospheric, or approximately atmospheric, pressure used in most boxes. Air saturated at 15 psi. above atmospheric pressure will have a relative humidity of only 50 per cent when expanded. Consequently the water necessary to saturate the air within the box must be supplied by evaporation. The higher the air pressure that is employed for atomization, the greater will be this evaporation effect. Both the liquid settling out of the mist, and the salt solution in the reservoir will then become more concentrated. If the necessary amount of water vapor is not added to the air during atomization, evaporation of water from the particles of mist may be sufficient to cause precipitation of salt crystals upon the samples and thus alter the corrosive attack. It has also been reported that excessive evaporation of water from the fog particles may result in the formation of a "dry fog," which does not readily wet the specimens.

Too much water in the air may be just as deleterious as too little. The air that is passing through the water-saturating tower may travel at a sufficient velocity to carry away with it appreciable amounts of entrapped moisture. If this water, together with that present as water vapor, is in excess of that necessary to obtain equilibrium within the box, dilution will occur, both of the salt solution in the reservoir and of the mist. Proper traps should therefore be placed in the air line immediately before the nozzle to remove any mechanically held water. The same effect may also result from condensation of water in the air lines leading to the box, particularly if the air has been heated appreciably above the room temperature.

A vent is necessary to permit excess fog to escape from the box and also to prevent an increase of pressure within the box. Such venting has been done more or less indiscriminately, depending largely upon convenience for the particular apparatus employed. However, it deserves more serious consideration since both the uniformity and density of the fog within the box may be adversely affected by improper venting.

It has long been recognized that fog density is an important factor and should be controlled rigidly if reproducible test results are to be secured. It is believed that with some classes of materials being tested the results will be consistent even though the density of the fog may vary over wide limits, while for other materials such variations may produce widely different results. Quantitative information along these lines is almost completely lacking. The test for measurement of fog density described in A.S.T.M. Tentative Method of Salt Spray Testing of Non-Ferrous Metals (B 117 - 41 T)[3] was based on the work of Tour. However, this test proved unsatisfactory, especially in those boxes in which the general movement of the fog was in a downward direction. Darsey's (15) modification of this test appears more promising and has been recommended for inclusion in new or revised specifications. It consists, essentially, in measuring the rate at which the liquid particles settle out of the mist by collecting the condensate in a container of prescribed horizontal cross-sectional area for a definite period. The volume of the condensate collected in unit time is a measure of the amount which would settle out on the samples under similar conditions of exposure. Standardization of the density of the fog by closely controlling such factors as nozzle size, air pressure, baffles, the shape and size of boxes, or methods of venting, is impracticable in a "working" standard.

OTHER CONSIDERATIONS

If the basic requirements of operation discussed above are strictly adhered to, the samples will be exposed at a constant temperature to a uniformly distributed dense fog of constant known composition. Its action is the result of settling by gravity and not of condensation of a gas into a liquid, as is sometimes assumed, since it is carried out at constant temperature. After a relatively short time the surface of the samples, if previously cleaned, should be uniformly covered with a fairly thin liquid film. To date there are no definite data to indicate that the settling of larger amounts of liquid upon the samples will give different results.

The preparation, positioning, and inspection of samples, while perhaps not basic requirements of the test, are important, and should be included in both the basic and the detailed specifications. Lack of consideration of these matters may result in erroneous and nonreproducible results even when all other factors are under exact control.

It is difficult to standardize upon the position of samples within a box. Because mist does not readily settle on a vertical surface, all flat samples should be placed at a slight angle from the vertical, preferably 15 deg. It is extremely difficult to realize this angle when irregular shaped objects are tested since their dominant or significant surfaces may lie in more than one plane. In such cases some system of rotation of the samples during test may be desirable, but this represents a specific problem and should be covered in detailed specifications. Inspection of the samples during a test should be made at short enough intervals to chart accurately the progress of corrosion. Procedures for handling and inspection of samples at the completion of a test, and the evaluation of results will probably vary with the different classes of materials tested and hence properly belong in the detailed specification.

SUMMARY

Increased use of the salt spray test has made it advisable to revise existing or conflicting specifications so that one standard method of conducting the test may be used. More attention must be exercised over some of the details of the testing procedures involved and greater control of some of the "variables" of the test is necessary if reproducible results are to be obtained by various testing laboratories. These requirements are discussed in the light of recent experiences with the test. The effects of some of the more important variables are discussed.

Acknowledgment:

Grateful acknowledgment is made of the cooperation of Miss S. V. Burdeshaw in this work.

REFERENCES

(1) J. A. Capp, "A Rational Test for Metal Protective Coatings," *Proceedings*, Am. Soc. Testing Mats., Vol. 14, Part II, p. 474 (1914).

(2) A. N. Finn, "Method of Making the Salt Spray Corrosion Test," *Proceedings*, Am. Soc. Testing Mats., Vol. 18, Part I, p. 237 (1918).

(3) H. S. Rawdon, A. N. Finn, and M. A. Grossman, "Protective Metallic Coatings for the Rustproofing of Iron and Steel," *Circular No. 80*, Nat. Bureau Standards, p. 24 (1919).

(4) H. S. Rawdon, A. I. Krynitsky, and W. H. Finkeldey, "Types of Apparatus Used in Testing the Corrodibility of Metals," *Proceedings*, Am. Soc. Testing Mats., Vol. 24, Part II, p. 728 (1924).

(5) E. C. Groesbeck and W. A. Tucker, "Accelerated Laboratory Corrosion Test Methods for Zinc-Coated Steel," *Journal of Research*, Nat. Bureau Standards, Vol. 1, No. 2, August, 1928, p. 255 (*RP 10*).

(6) H. S. Rawdon and E. C. Groesbeck, "Effect of the Testing Method on the Determination of Corrosion Resistance," *Technical Paper No. 367*, Nat. Bureau Standards, March 6, 1928.

(7) P. W. C. Strausser, A. Brenner, and W. Blum, "Accelerated Tests of Nickel and Chromium Plating on Steel," *Journal of Research*, Nat. Bureau Standards, Vol. 13, No. 4, October, 1934, p. 519 (*RP 724*).

(8) W. H. Mutchler, R. W. Buzzard, and P. W. C. Strausser, "Salt Spray Test," *Circular Letter No. 530*, Nat. Bureau Standards, July 1, 1938.

(9) Reports of Committee B-3, on Corrosion of Non-Ferrous Metals and Alloys, *Proceedings*, Am. Soc. Testing Mats., Vol. 24, Part I, p. 281 (1924); Vol. 25, Part I, p. 150 (1925); Vol. 32, Part I, p. 201 (1932).

(10) Report of Subcommittee III on Conformance Tests of Committee B-8, *Proceedings*, Am. Soc. Testing Mats., Vol. 43, p. 187 (1943).

(11) C. H. Sample, "Use and Misuse of the Salt Spray as Applied to Electrodeposited Metallic Finishes," ASTM BULLETIN, No. 123, August, 1943, p. 19. Discussion, p. 22.

(12) "Summary of Important Factors in Salt Spray Testing," *Circular No. 670*, Scientific Section, National Paint, Varnish, and Lacquer Assn., Inc., February, 1944.

(13) C. E. Heussner, "Comparison of Salt Spray and Ocean Spray Testing," *Proceedings*, Educational Sessions, Am. Electroplaters' Soc., June 8, 1942, p. 75.

(14) E. H. Dix, Jr., and J. J. Bowman, "Salt-Spray Testing," Symposium on Corrosion Testing Procedures, Chicago Regional Meeting, Am. Soc. Testing Mats., p. 57 (1937). (Symposium issued as separate publication.)

(15) V. M. Darsey, "The Salt Spray Test," ASTM BULLETIN, No. 128, May, 1944, p. 31.

DISCUSSION

Mr. Sam Tour[1]—Since the salt spray test has been something which Committee B-3 has had under consideration during the years I have been its chairman, I feel compelled to discuss this paper.

The present revision of Methods B 117 on salt spray testing presented at this annual meeting[2] incorporates in it practically all of the changes which would be inferred as recommended by the paper that has just been presented.

Personally, it is with crossed fingers that I see some of the things that have been incorporated in this specification. Hindsight is always better than foresight. It may be that we have gone a bit too far in setting up some new requirements in salt spray testing in the way of prescribing the fog density method according to Mr. Darsey.[3]

As Mr. Waldron pointed out, some years ago I proposed a fog calibrating method for salt spray testing. It worked on one type of apparatus but I found that it did not work on another type. It so happens that the other type on which it did not work is the more popular type of today.

Mr. Darsey's modifications of that fog trap method is a modification particularly suitable to the most popular type of salt spray equipment of today. I am afraid that it will throw out of use the older types of salt spray equipment. Time and experience will tell.

I should like to comment on one other thing about the new salt spray test specification and the paper by Mr. Waldron.

About five years ago I began calling attention, strongly, to the question of temperature within the box of the salt spray and the cooling effect at the nozzle in creating the spray. I had built, I think, one of the first if not the first hot-water tower saturation attachments for salt spray in order to saturate the compressed air at an elevated temperature and avoid that cooling effect at the nozzle.

That modification of salt spray equipment is incorporated in the present specifications and it is now a simple matter to install equipment to control the temperature at the nozzle.

Mr. A. H. Reynolds.[4]—I should like to ask Mr. Waldron whether the question of the heating of the box internally or externally has been taken up.

As I understand it, the Bureau of Standards has done some work in conjunction with the paint manufacturers on the salt spray cabinet and I think it was the recommendation, at least in the bulletin presented by the paint manufacturers, that the cabinet would have to be heated externally, and that heating the cabinet internally was the principal cause of disagreement in results.

Mr. Leo J. Waldron[5] (*author's closure, by letter*).—The comments of both of the discussors are appreciated. Mr. Tour is fully justified in pointing out uncertainties concerning some of the features now being incorporated in various specifications covering this test, particularly "fog-collection" methods. These requirements were proposed after considerable deliberation on the part of those present at the two meetings last spring in Washington. Limited experimental data at that time precluded a definite answer as to the ultimate utility of the method and the exact limits which should be specified. All agreed, however, that it was a step in the right direction and worthy of consideration. Time and experience may indicate some changes in the details to be desirable. Several months' experience at the National Bureau of Standards with the method as a daily requirement would indicate that the manipulation is simple and the result gives a measure of the effectiveness of operation of any specific box. Further, it has been noted, that with a few specific materials thus far investigated, a minimum settling rate is necessary, apparently, if consistent and reproducible corrosion results are to be obtained in salt spray tests.

---

[1] President, Sam Tour & Co., Inc., New York, N. Y.

[2] 1944 Book of A.S.T.M. Standards, Part I, p. 1843.

[3] V. M. Darsey, "The Salt Spray Test," A.S.T.M. Bulletin, No. 128, May, 1944, p. 31.

[4] Directing Chemist, Dearborn Chemical Co., Chicago, Ill.

[5] Metallurgist, National Bureau of Standards, Washington, D. C.

The work to which Mr. Reynolds referred was carried out by the Office of the Quartermaster General and the suggestion was made as a result of their investigation that the temperature used in this test be controlled by external rather than internal means. They attributed wide variations in corrosion behavior to relatively large temperature gradients existing within a box when an internal heating method was employed. The revised edition of A.S.T.M. Tentative Method B 117, covering the salt spray test, specifies the temperature requirements to be met but leaves it optional with the individual operator as to exact means for its accomplishment. Any means which permits temperature variations within the limits as specified could be properly employed.

MICRO-DEFORMATION UNDER TENSION AND COMPRESSION LOADS OF THIN ALUMINUM ALLOY SHEETS FOR AIRCRAFT CONSTRUCTION*

By Georges Welter[1]

Synopsis

This paper presents test results on the stress characteristics for micro-elastic and micro-plastic deformations as well as the modulus of elasticity of thin aluminum alloy sheets in tension and compression. The sheets were analyzed for seven different angles to the direction of rolling and cold streching as well as over the whole width. The investigation, which consisted in submitting the specimens to tension stresses, succeeded by compression, showed results which are of interest to the designer and constructor of modern monocoque structures. A new gripping device for tension tests and a special device for compression tests on single thin specimens have been developed.

This paper covers part of an investigation[2] conducted at the École Polytechnique, Montreal, concluded November 1942, to obtain some basic information concerning the mechanical behavior of thin aluminum alloy sheets under axial thrust. It is well known that a determination of the stress-strain functions under compressive loads is urgently needed for thin sheets used in aircraft constructions because their mechanical properties, especially their micro-deformations under compressive loads, differ appreciably from those under tensile loads. In view of the importance of the anisotropy (direction of rolling) of the sheets and their elastic stability in connection with economic use of the material in aircraft, special consideration was given to the elastic characteristics, such as Young's modulus of elasticity, as well as the micro-elastic and micro-plastic properties of this material. Besides these values, the usual properties of yield strength, ultimate strength, and elongation were measured.

Three sheets (designated D, A, and B), commercial products of the Aluminum Company of Canada, were tested as follows:

1. At seven different angles to the direction of rolling and cold stretching;
2. Over the whole width of the sheets; and
3. Over a distance from about 8 to 25 in. in the direction of rolling.

In making these tests for the determination of the values of the main directional properties, at least two and up to ten identical tests were conducted.

Besides tension tests, generally used in this kind of investigation, a more delicate

---

* The author appreciates the assistance of J. Hurtubise and R. Frigon and other members of the staff of the research laboratory, in the execution of this work.

[1] Professor of Applied Mechanics, École Polytechnique, University of Montreal, Montreal, Canada.

[2] The other part will be published under the title of "Curved Aluminum Alloy Sheets in Compression," in the *Journal of the Aeronautical Sciences*, 1944.

study of the behavior of these thin sheets under compressive loads was undertaken. Such compressive tests seemed necessary for a complete understanding of the mechanical properties of the material in connection with its practical application in stressed skin constructions. Also an investigation of successive stresses, as tension succeeded by compression and *vice-versa*, showed interesting effects (Bauschinger-effect), which cannot be ignored in the design and construction of modern monocoque structures operating under similar conditions.

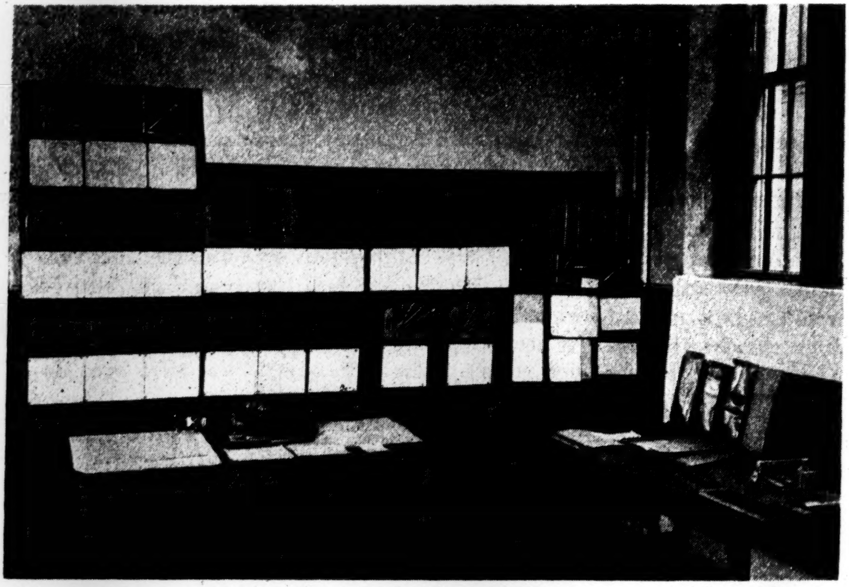


FIG. 1.—Layout of Results of Tests in Tension and Compression on Different Sheets.

Accordingly the following tests were made on thin aluminum alloy sheets 17S-T (thickness 0.032 in.):

1. Anisotropy and directional characteristics under tension and compression, measuring Young's modulus of elasticity, the elastic limit with 0.001 per cent micro-deformation, the stresses at 0.01 and 0.1 per cent permanent set, the yield strength (0.2 per cent set), and the tensile strength and elongation parallel, transverse, and at 15, 30, 45, 60, and 75 deg. to the direction of rolling (Fig. 1).

2. Bauschinger-effect and micro-plastic deformation in tension and compression, observed in single test specimens.

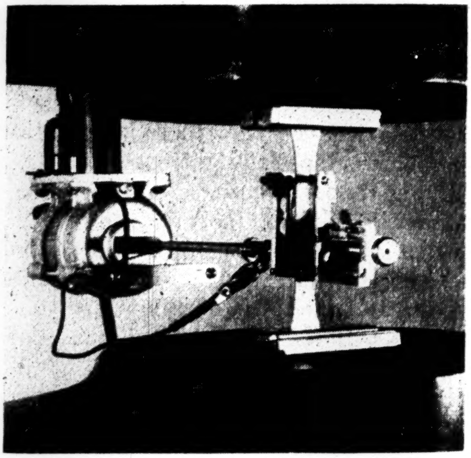


FIG. 2.—Templin Recorder Adjusted on the Aluminum Alloy Specimen in Tension.

Description of Apparatus and Material Tested:

Preliminary tests were conducted in order to find out the best technique for preparing and adjusting the test specimens. These tests were made on a 60,000-lb. capacity Baldwin-Southward-Tate-Emery Universal testing machine, having a guaranteed accuracy of less than ½ per cent of the load. The loading range used for most of these tests was of about 2400 lb. capacity with 2-lb. dial divisions. For the investigation of the elastic directional properties and the micro-plastic and other mechanical properties, the Templin extensometer (Fig. 2) and stress-strain recorder were used. The sensitivity of this recorder is of the order of about 0.00001 in. per inch for a 2-in. gage length. Numerous stress-strain diagrams, similar to Fig. 3, were recorded in several series.

The normal method of suspending the test specimens by means of flat grips was replaced, as will be seen in Figs. 4 and 5, by suspending the specimens by means of special grips which applied the stress through 10-mm. balls in order to secure ideal axial loading through the longitudinal axis of the very thin flat specimen. Numerous comparative tests clearly demonstrated the superiority of the new grips over the usual technique, so far as reliability of results of micro-deformation in tension is concerned.

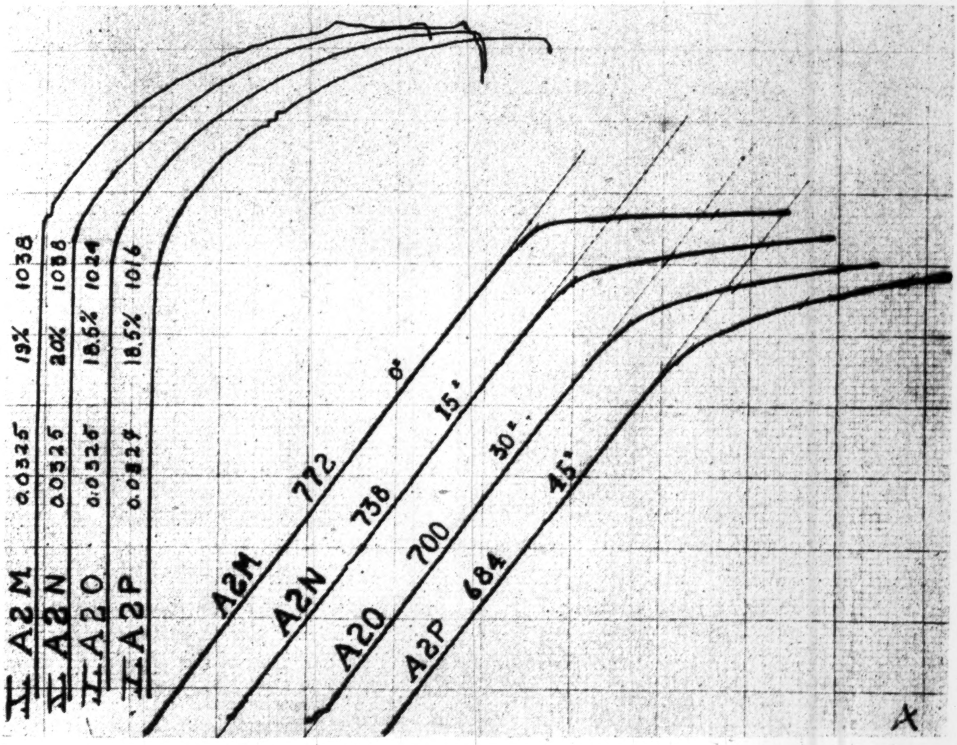


FIG. 3.—Stress-Strain Record in Tension; Elastic and Micro-Plastic Deformations at 0 to 45 deg. to the Direction of Rolling.

On the other hand, for compression

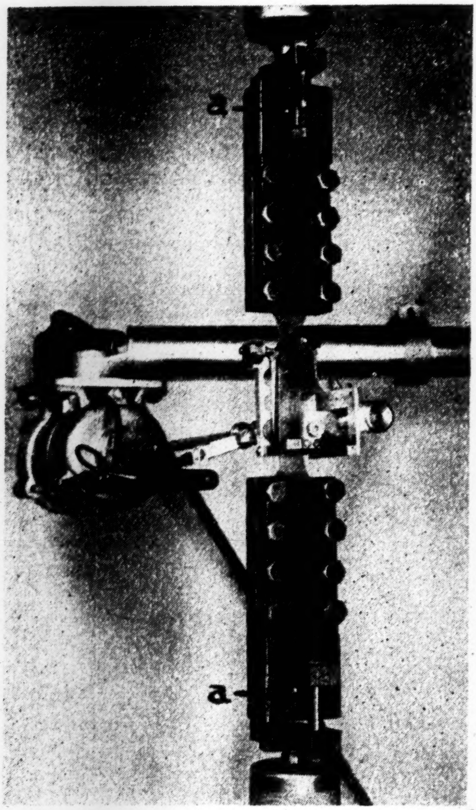


FIG. 4.—Thin Test Specimen with Extensometer.

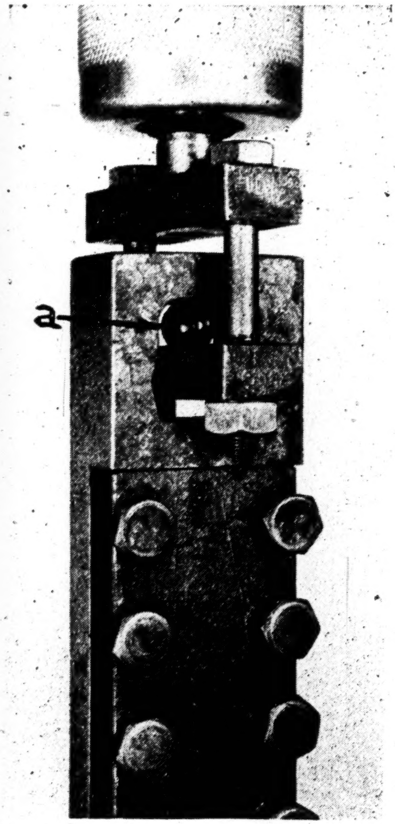


FIG. 5.—Upper Test Grip with Universal Joint on Steel Ball.

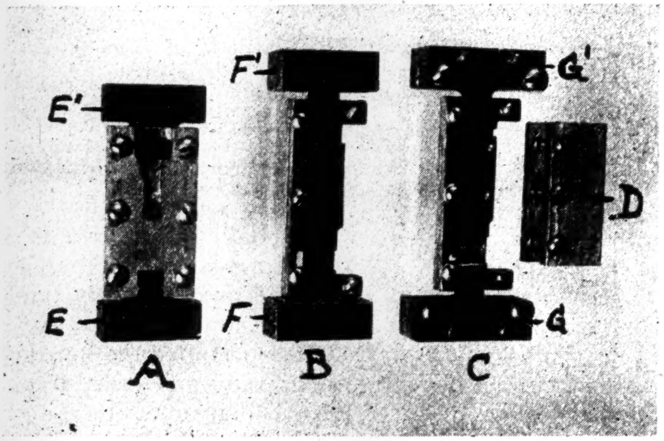


FIG. 6.—Devices for Compression Test of Single Thin Specimens (Three Different Models).

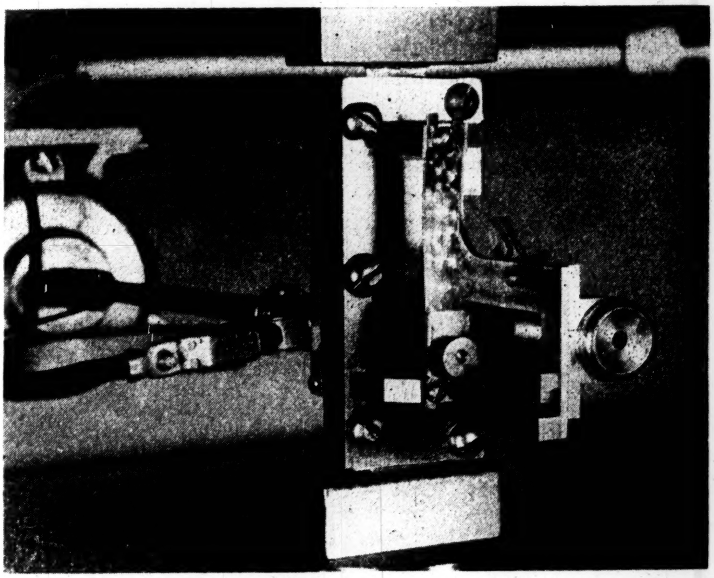


FIG. 7.—Templin Extensometer Adjusted on Specimen Under Compression.

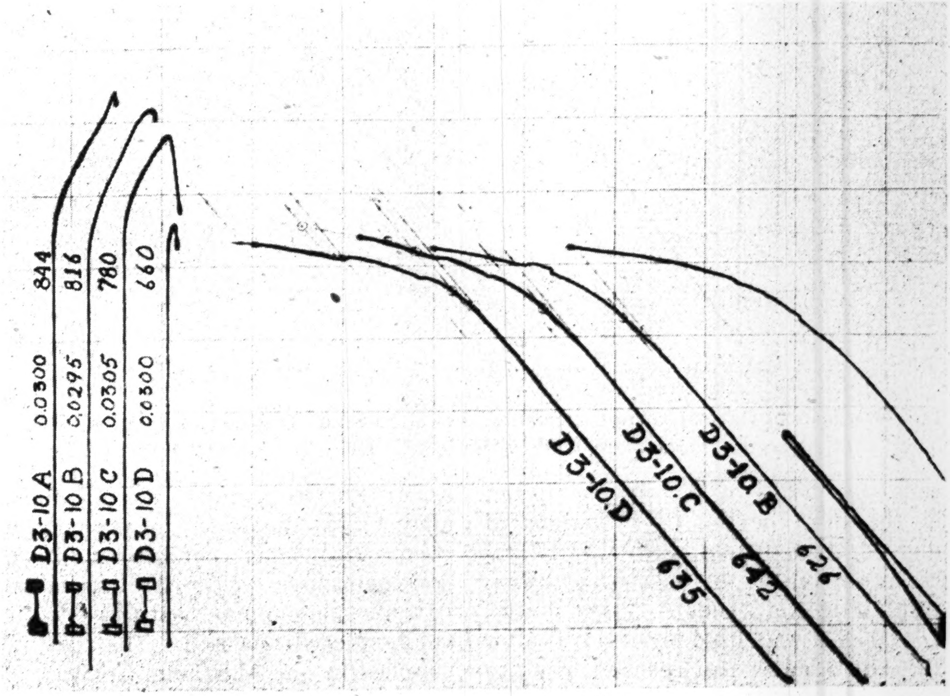


FIG. 8.—Original Compression Diagram; Diagram of Micro-Deformations and Normal Stress-Strain Records

tests, used in investigating the Bauschinger-effect, completely new testing devices were designed and manufactured in order to prevent premature buckling of the test specimens. In two devices, shown in Fig. 6 *A* and *B*, the compressive load was applied by means of small platens (*E-E′* and *F-F′*) fixed to test specimens of ½ in. in width (¾-in. width ends) by means of Wood's metal, and in the third device, *C*, by means of divided steel platens, (*G-G′*) fixed mechanically on the test specimens of ½-in. width (¾-in. width ends). A steel sheath, *D* of Fig. 6, was fixed on device *C* after the extensometer had been removed, to aid in supporting the divided device in resisting buckling. A general view of these devices, designed to use either the Huggenberger or Templin extensometers, is given in Fig. 7, while some original compression diagrams, recorded with this latter device, are shown in Fig. 8. By this means, the stress-strain diagrams could be recorded for the compression of thin sheets up to the buckling load of the test specimen.

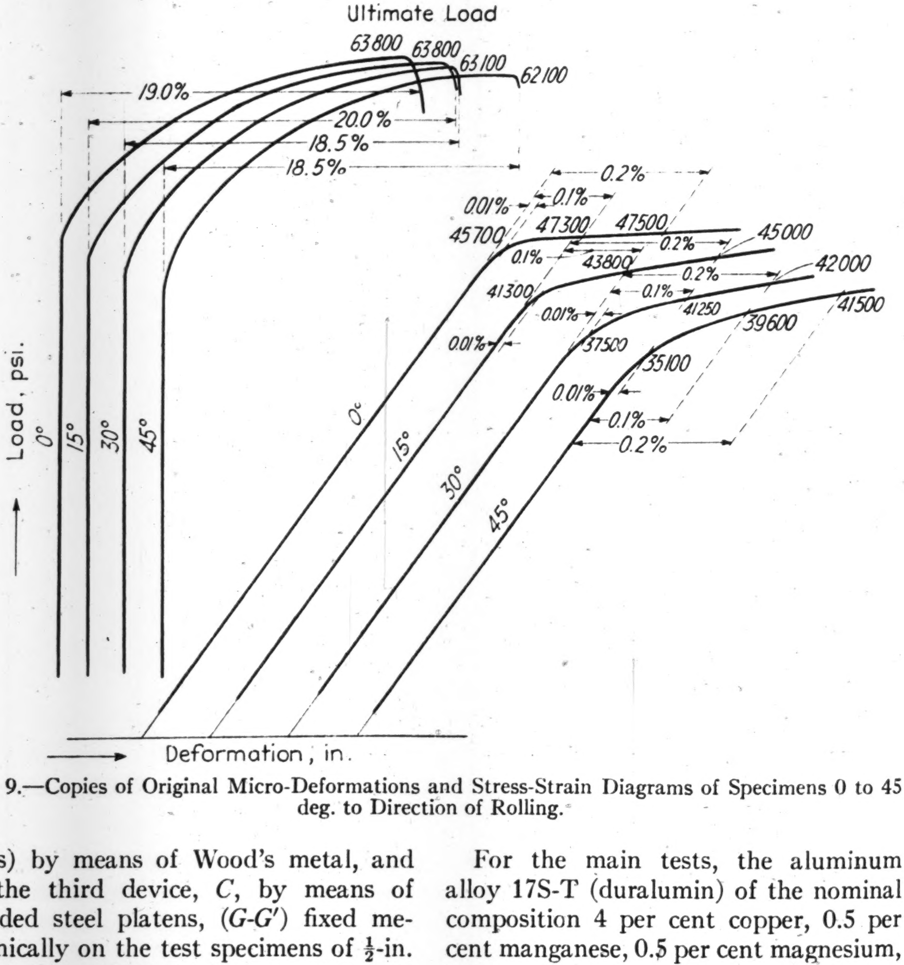


FIG. 9.—Copies of Original Micro-Deformations and Stress-Strain Diagrams of Specimens 0 to 45 deg. to Direction of Rolling.

For the main tests, the aluminum alloy 17S-T (duralumin) of the nominal composition 4 per cent copper, 0.5 per cent manganese, 0.5 per cent magnesium, balance aluminum, heat-treated and cold-stretched, was used. This alloy was supplied by the Aluminum Company of Canada in 1942, in sheets of two different dimensions: two sheets 0.032 in. thick, 86 in. long, and 36 in. wide, and four sheets 0.032 in. thick, 72 in. long, and 24 in. wide. The two larger sheets were anodized to prevent corrosion, having a darker color than the unprotected smaller sheets. All sheets were delivered commercially flat, but not completely free from small injurious surface defects.

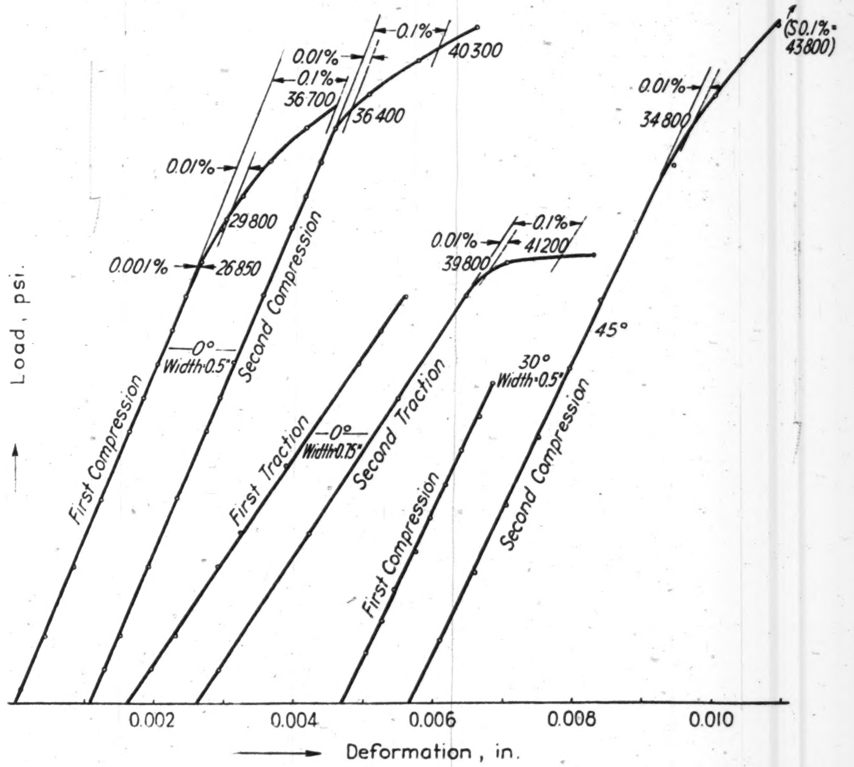


FIG. 10.—Micro-Deformation in Tension and Compression Obtained with Huggenberger Extensometer.

The test specimens were cut from these sheets by means of an automatic jigsaw, care being taken to produce no local deformation or cold working effect due to the machining process. The edges of the larger plates, after they have been cut out of the sheets, were, if necessary, smoothed by filing. On the other hand, the smaller test specimens for tension and compression tests, after they had been cut out of the sheets by means of this saw, were brought to the final shape in bundles of 10 to 15 pieces, by hand filing or by milling on an automatic milling machine. The dimensions of these test specimens were made to conform closely to the standard test specimen for sheet metals, according to A.S.T.M. Tentative Specification for Aluminum-Alloy (Duralumin) Sheet and Plate (Aluminum - Copper - Magnesium - Manganese) (B 78 – 42 T).[3] Most of these specimens for tension and compression had a reduced section of about $2\frac{1}{2}$ in. long and $\frac{1}{2}$ in. wide.

The tension tests have been executed in accordance with the methods recommended by the A.S.T.M.

---

[3] 1942 Book of A.S.T.M. Standards, Part I, p. 1143.

RESULTS OF TESTS

The results of these tests are presented graphically, in so far as possible, which in most cases are self-explanatory.

Anisotropy and Directional Properties in Tension and Compression:

From each test specimen a micro- and a macro-load-deformation diagram was recorded during the test and from these diagrams Young's modulus of elasticity, the stresses at 0.01 and 0.1 per cent permanent deformation, and the yield strength (0.2 per cent set) were calculated as illustrated by Fig. 9, which also shows on copies of the original records the method of determining the mechanical characteristics. In the same way, the stresses under compressive loads were calculated. The elastic limit and micro-deformations were controlled by means of the Huggenberger extensometer, capable of indicating a minimum deformation of 0.001 per cent. Two of these instruments were fixed on the test specimen, prevented from buckling by means of a steel sheath. For sheet A at 0.001 per cent deformation the stress was 26,850 psi. and for 0.01 per cent about 29,800 psi. These results correspond fairly well with the same values measured by the Templin extensometer. Fig. 10 shows some values for micro-deformation measured on specimens at 30 and 45 deg., as well as on specimens at 0 deg. in tension and compression, by means of Huggenberger extensometers.

In Fig. 11 are presented comparative results of these tension and compression tests for the three sheets, showing the effect of the angle of the test specimens with the direction of rolling. Based on these diagrams, it can be stated that all mechanical properties of rolled aluminum alloy sheets depend more or less on the angle between the specimen and the direction of rolling. This directionality is limited for the ultimate strength to between about 63,000 and 61,000 psi., showing a maximum in the direction of rolling. In all cases, at least 4 to 5 per cent reduction in strength was noted between 30 and 60 deg. as shown in Fig. 11.

There was no consistent relation between the elongation and the position of a test specimen in the sheet. Elongations between 18 and 20 per cent for the sheets D and A and between 20 and 21 per cent for sheet B have been measured.

On the other hand the yield strength (0.2 per cent set) as well as the stress at 0.1 per cent deformation are highly dependent on the angle of the test specimen with the direction of rolling. A greater influence was found in all cases for the 0.1 per cent limit. For sheet B for instance there was up to about 20 per cent lower resistance for 75 and 90 deg., as compared to that in the direction of rolling. The difference in yield strength was about 15 per cent.

The stresses at 0.01 per cent deformation vary even more markedly, reaching their minimum value at an angle of more than 45 deg. with the direction of rolling. As may be seen from Fig. 11, values at 60 deg. were 20 per cent less in the case of sheets D and A and even up to 35 per cent less in the case of the sheet B.

The percentage differences in the micro-plastic characteristics with a permanent set of 0.01, 0.1 and 0.2 per cent are represented graphically in Fig. 12. These changes are appreciable; for example, in the tension test, beginning with an angle of 40 deg., for a permanent set of 0.01 per cent there is a variation of over 20 per cent. The maximum difference in tension (about 35 per cent) was found in the case of sheet B in the direction of about 70 deg. In tension and compression there was up to 32 per cent difference between the values taken in

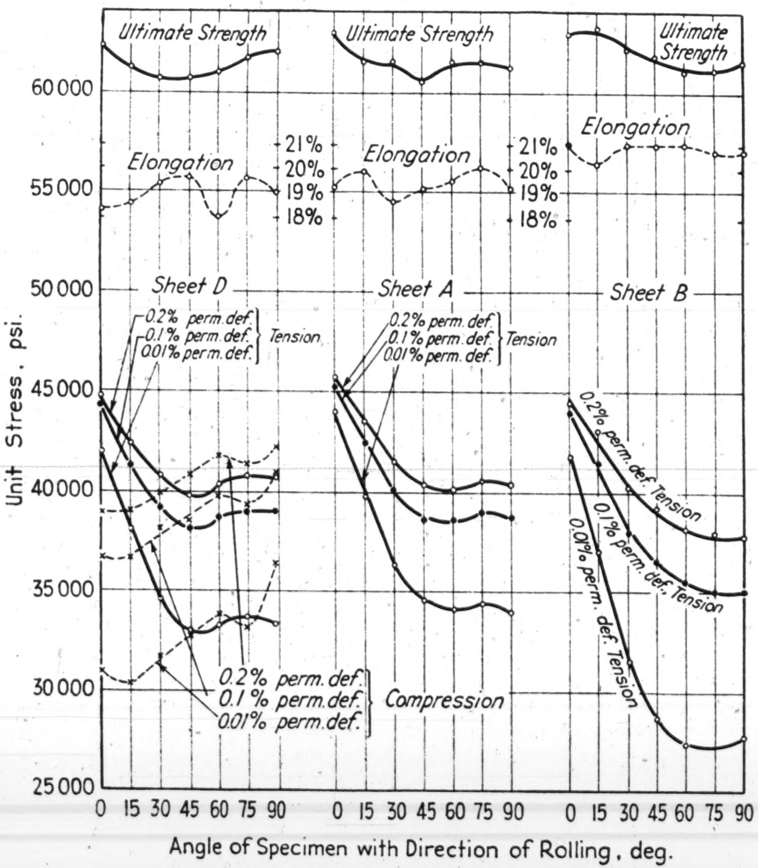


FIG. 11.—Directionality of Mechanical Characteristics in Tension and Compression.

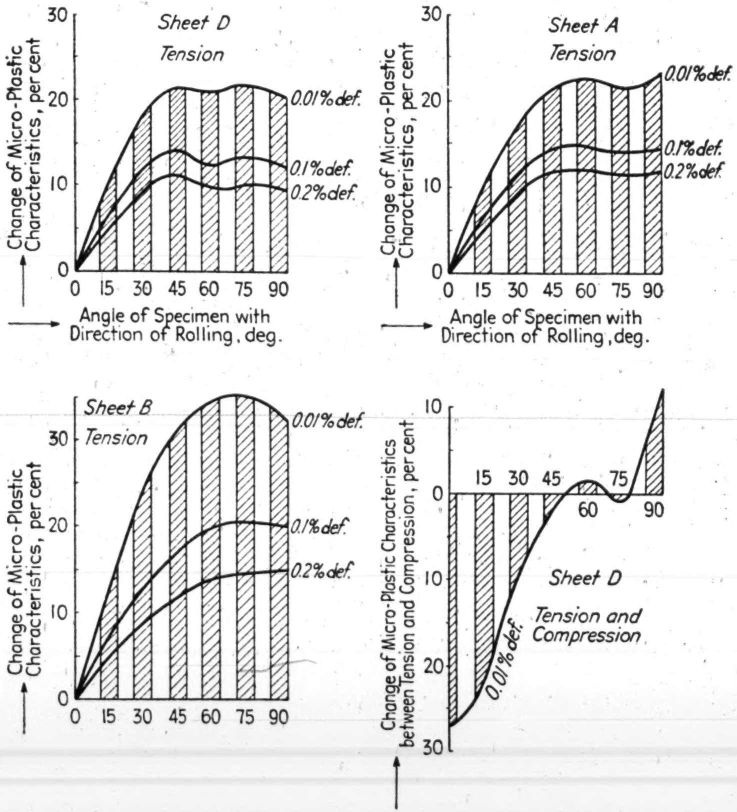


FIG. 12.—Change of Micro-Plastic Characteristics in Function of Angle of Specimen with Direction of Rolling.

the direction of rolling and at right angles thereto.

The stresses responsible for very small deformations seem to play a predominant role in the resistance of thin sheets in form of panels to compressive loads; the buckling phenomenon of these sheets in stressed skin constructions in airplanes is highly dependent upon this characteristic. The buckling effect can usually be observed at compressive stresses far below the yield stress in tension or even in compression. Since in the restrained parts of the panels, however, the buckling stresses may be high enough to result in permanent strain, it is evident that the investigation of the mechanical properties of these alloys in terms of the micro-deformations in relation to the applied loads is of primary importance. It is not sufficient to measure the tensile or compressive yield strength at a permanent set of 0.2 per cent; it is far more important to know which tensile or compressive stresses correspond to the permanent deformation of 0.1 per cent, 0.01 per cent, and even at 0.001 per cent. It was to secure some information about these stresses that the present tests were made.

As a matter of interest, some comparative results on relation of direction of rolling recently published by the Army-Navy Civil Committee (ANC-5, Dec. 1942) are shown in Table I.

TABLE I.

Property	Angle With Direction of Rolling, deg.	RESULTS			
		École Polytechnique		Army Navy Civ. Committee ANC-5	
		Factor × Property	Angle With Direction of Rolling, deg.	Factor × Property	Angle With Direction of Rolling, deg.
Tensile strength	0	1.0 ÷ 1.02 × ten. str.	90	1.02 × ten. strength	90
Tensile yield strength	0	1.08 ÷ 1.19 × ten. yield	90	1.17 × ten. yield	90
Tensile permanent deformation, 0.01 per cent set	0	1.24 ÷ 1.56 × ten. yield perm. def. 0.01 % set.	90	.....	..
	0	1.35 × comp. perm. def., 0.01% set	0	.....	..
Compression yield strength	0	0.94 × ten. yield	90	0.96 × ten. yield	90
	0	0.92 × comp. yield	90	$\frac{0.96}{1.08}$ = 0.89 × comp. yield	90
	90	1.03 × ten. yield	90	1.08 × ten. yield	90
	0	0.86 × ten. yield	0	$\frac{0.96}{1.17}$ = 0.82 × ten. yield	0
Compression permanent deformation 0.01 per cent set	0	0.85 × comp. perm. def., 0.01% set	90	.....	..
	0	0.74 × ten. perm. def., 0.01% set	0	.....	..
	0	0.92 × ten. perm. def., 0.01% set	90	.....	..
	90	1.09 × ten. perm. def., 0.01% set	90	.....	..
	45	1.0 × ten. perm. def., 0.01% set	45	.....	..

The results obtained at the École Polytechnique correspond fairly well with the results given in the ANC report for tensile strength and compression yield with and transverse to the direction of rolling. Furthermore this table shows clearly the rather important difference between the compression and tension factors for permanent deformations of 0.01 per cent.

The very pronounced directionality of

these important mechanical properties is primarily due to the stretching or flattening process of the sheets during manufacturing. In this process, in order to secure reasonably flat sheets, they are given after heat treatment about 1 or 2 per cent permanent set by cold stretching. This, coupled with a certain directionality due to rolling, is the principal cause of the higher tensile resistance under micro-deformations and the higher tensile yield strength in the direction of rolling as compared with those at 45 deg.

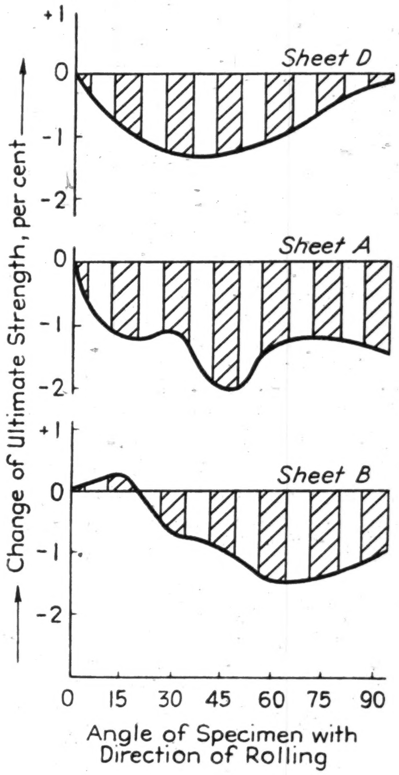


FIG. 13.—Change of Ultimate Strength of Specimen with Direction of Rolling.

It is evident that the resistance of these stretched materials is less with respect to stresses in the opposite direction, that is to compressive loads. This is illustrated in Fig. 11 for sheet D. Tests showed that the yield strength in compression in the direction of stretching was about 6000 psi. lower than that in tension; for 0.01 per cent deformation it was as much as 11,000 psi. less. In the case of sheet D, difference in this respect between tension and compression was as much as 27 per cent (Fig. 12). In the case of sheet B with a high directionality of the stresses in tension at micro-deformation between 0 and 60 deg., it is probable that this percentage between tensile and compressive stresses would have been even greater.

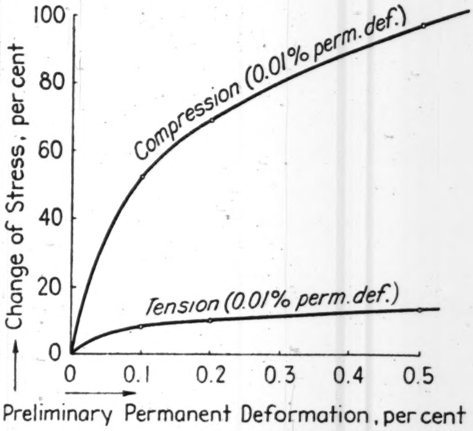


FIG. 14.—Change of Stress (0.01 Per Cent Permanent Deformation) in Function of Preliminary Permanent Deformation.

Figure 13 represents the anisotropy of sheet D, A, and B with regard to ultimate strength.

Preliminary Micro-Deformation and Its Effect on the Increase of the Elastic Properties:

These tests show the high sensitivity under compressive loads of sheets cold stretched after heat treatment. According to results in alternating tension-compression cycles, on single test specimens, it may be seen in Fig. 14 that a

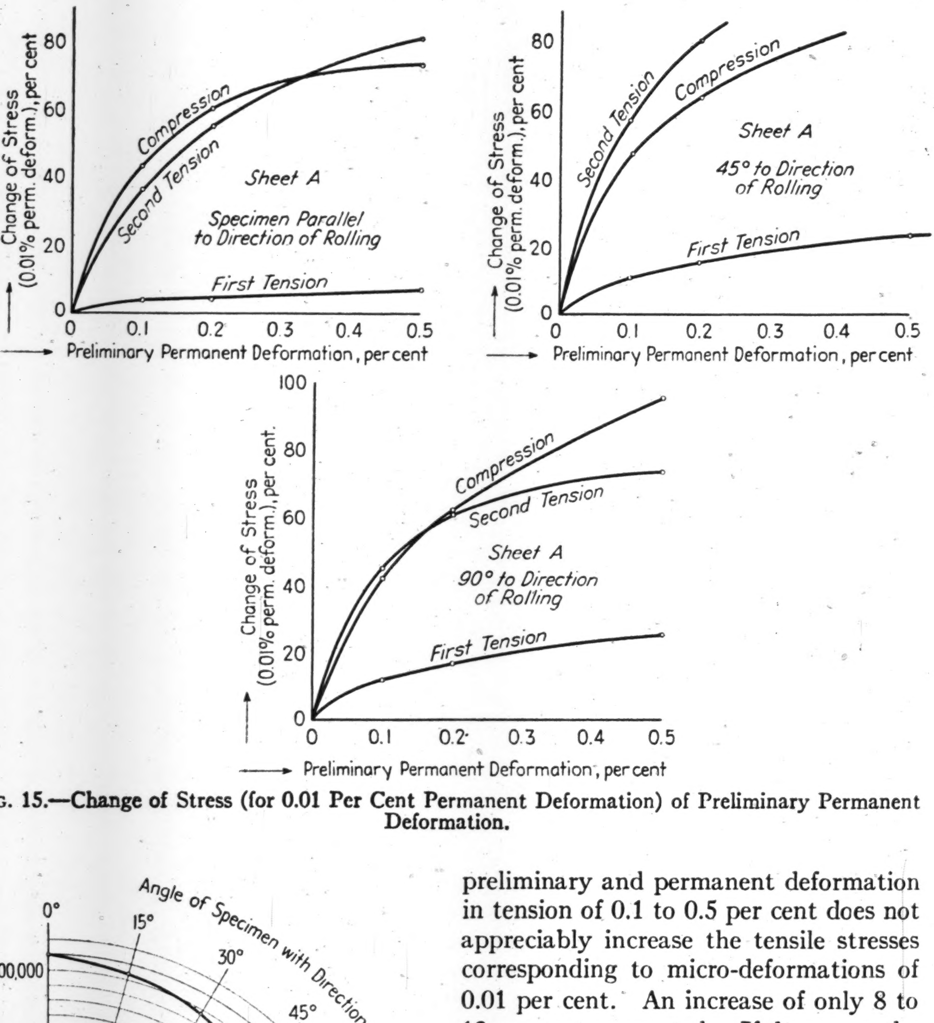


FIG. 15.—**Change of Stress (for 0.01 Per Cent Permanent Deformation) of Preliminary Permanent Deformation.**

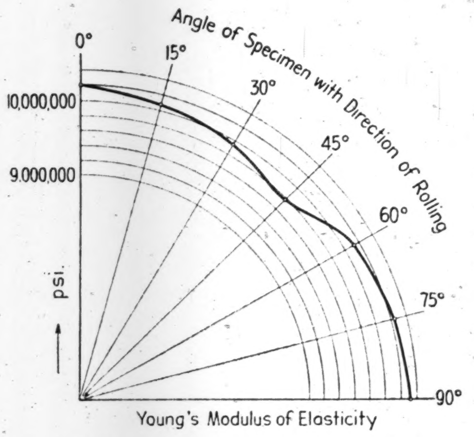


FIG. 16.—**Young's Modulus of Elasticity in Function of Rolling Direction—Sheet D.**

preliminary and permanent deformation in tension of 0.1 to 0.5 per cent does not appreciably increase the tensile stresses corresponding to micro-deformations of 0.01 per cent. An increase of only 8 to 12 per cent was noted. If, however, the test specimens are subjected to compressive stresses, a preliminary deformation of 0.1 per cent causes a change of more than 50 per cent in the 0.01 per cent limit, of about 68 per cent in the 0.2 per cent, and of about 96 per cent in the 0.5 per cent permanent deformation. Fig. 15 gives similar results for the duralumin sheet A at angles of 0, 45, and 90 deg. to the direction of rolling.

Young's Modulus of Elasticity:

The modulus of elasticity for sheet D calculated from the stress-strain diagram, is reproduced in Fig. 16 on a polar diagram. As this diagram shows, this aluminum alloy, in contrast to other metals such as copper, for which Young's modulus was found to vary as much as 100 per cent (**2**)[4], is not greatly influenced by cold rolling and stretching. A difference of only 4 to 5 per cent of the average values was measured on specimens at 45 deg. to the direction of rolling. At this angle, Young's modulus of elasticity was less than 9,800,000 psi. as compared to 10,200,000 psi. parallel and 10,300,000 psi. transverse to the direction of rolling. This is in accord with the findings of A. E. Bryukhanow (**3**), who reported a difference of 6 per cent in the modulus of elasticity values. Fig. 17 is another polar diagram showing Young's modulus of elasticity in relation to the direction of rolling of sheets A and B.

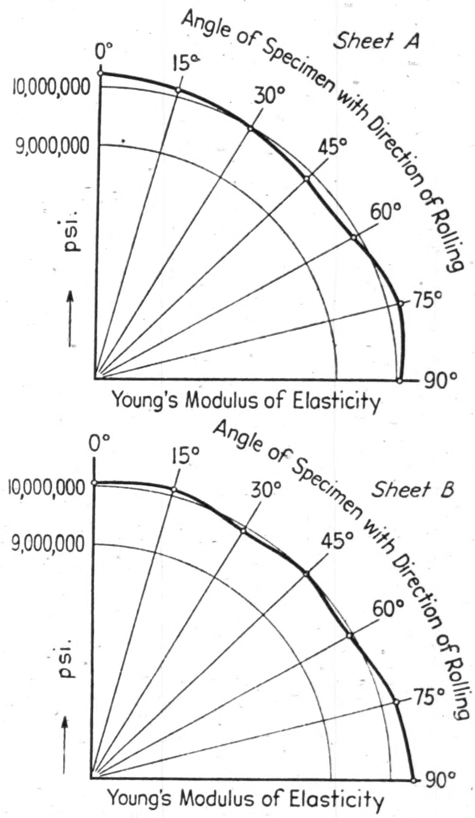


FIG. 17.—Young's Modulus of Elasticity in Function of Rolling Direction—Sheets A and B.

Bauschinger-Effect:

As mentioned above, the resistance of the aluminum alloy sheets to compressive loads was relatively small. This property, an interesting characteristic of all metals and alloys showing some plasticity, is known as the Bauschinger-effect. In Figs. 18 to 21 are given the results of alternating tension-compression tests on specimens cut from sheets D and A in the direction of rolling and at 45 and 90 deg. to this direction. Figure 18 shows stress-strain diagrams for a specimen taken from sheet D in the direction of rolling. After the 0.01 per cent limit was reached at about 40,000 psi. (point *A*), the loading was discontinued at a somewhat higher stress and the specimen unloaded to point *B*. Upon loading a second time (*B*—*C*) it became evident that, due to the preliminary stressing, this 0.01 per cent limit was now higher (about 42,000 psi.). The 0.1 per cent limit was found to be of about 43,400 psi. and the yield strength at 0.2 per cent set was of the order of 44,100 psi. When the loading was again interrupted at point *D* and lowered to *E*, and the specimen was again loaded (*EF*), then the 0.01 per cent limit of permanent set was found to be in the neighborhood of the yield strength (about 44,000 psi.). A yield point of 0.5 per cent set corresponds to a stress of 45,400 psi. After the total deformation of about 0.5 per cent at point *G*, the

---

[4] The boldface numbers in parentheses refer to the papers appearing in the list of references appended to this paper, see p. 681.

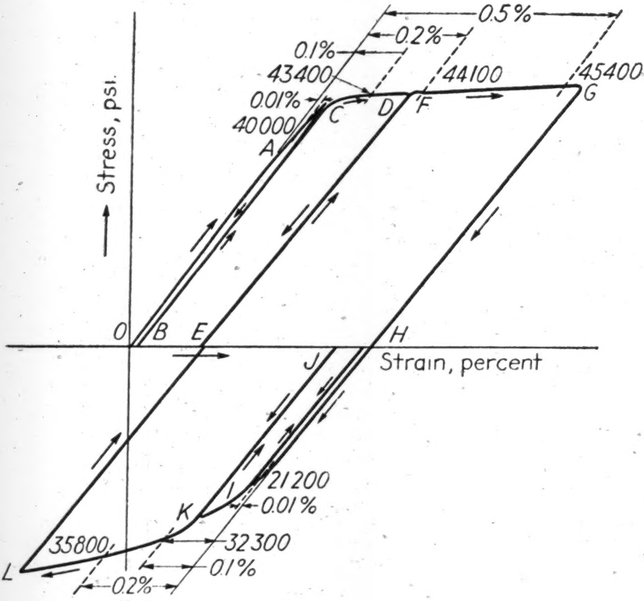


FIG. 18.—Micro-Deformation Under Tension and Compression Loads. Sheet D Parallel to Direction of Rolling.

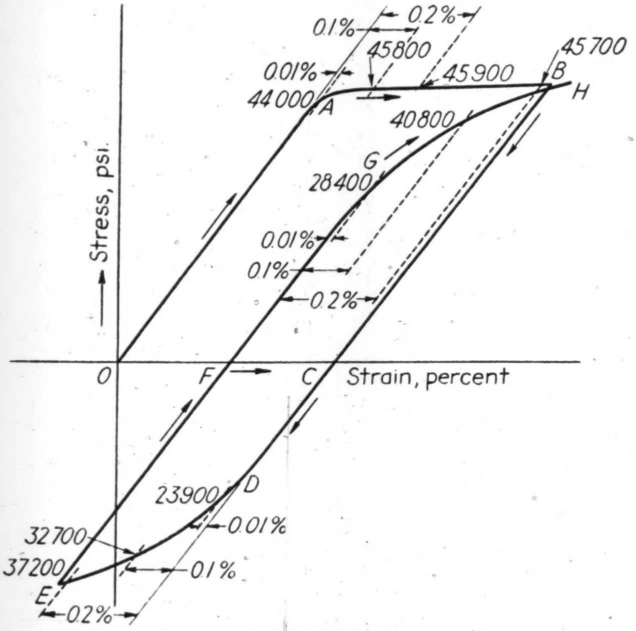


FIG. 19.—Micro-Deformation Under Tension and Compression Loads. Sheet A Parallel to Direction of Rolling.

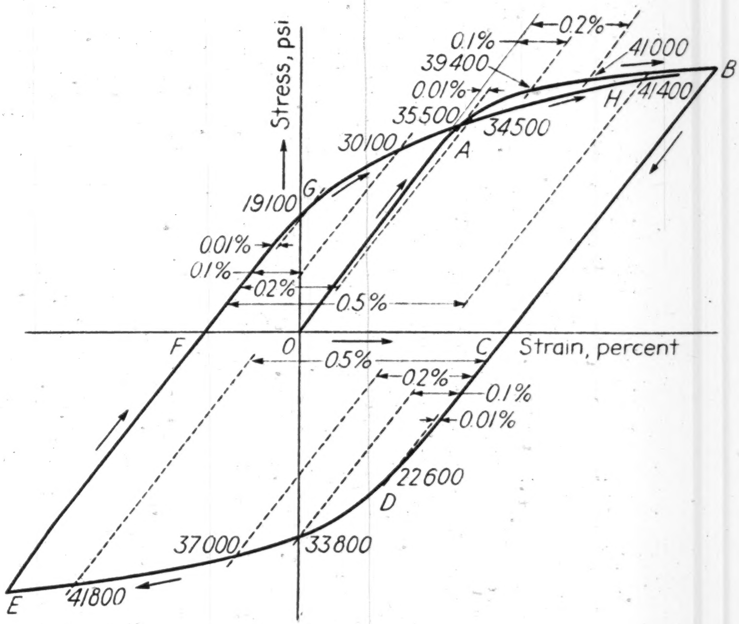


FIG. 20.—Micro-Deformation Under Tension and Compression Loads. Sheet A 45 deg. to Direction of Rolling.

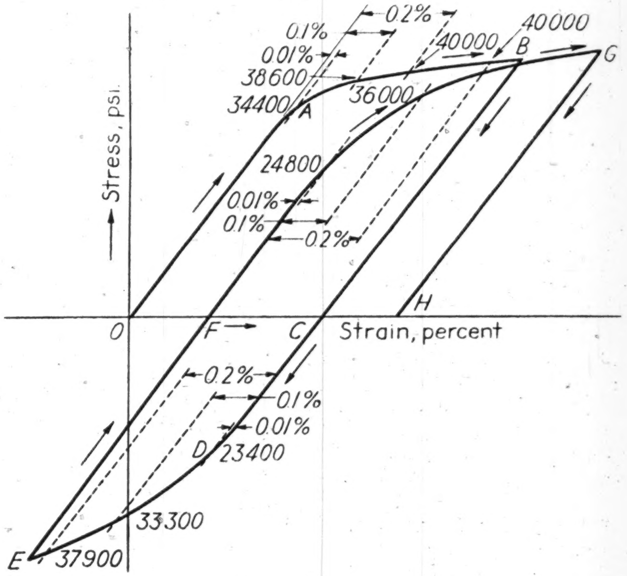


FIG. 21.—Micro-Deformation Under Tension and Compression Loads. Sheet A 90 deg. to Direction of Rolling.

specimen was unloaded to point *H*. After this tension test, the same test specimen was placed in the steel sheath referred to earlier, and again loaded, this time in compression (*HI*) until the 0.01 per cent limit of deformation was reached. This limit, extremely low as compared to its value in tension, was only 21,200 psi. as compared to 40,000 psi. in tension. Discontinuing the loading, then unloading and reloading to point *I*, this limit became gradually higher and approached the 0.1 per cent limit at 32,300 psi., at point *K*, or the yield strength (0.2 per cent set) at 35,800 psi. It is interesting to note that even this yield strength in compression of 35,800 psi. is much lower than the limit with only 0.01 per cent deformation at 40,000 psi. in tension.

Analogous Bauschinger-effect diagrams for sheet A at 0, 45, and 90 deg. are shown in Figs. 19 to 21. The elastic limit of 0.01 per cent deformation of this sheet (Fig. 19) was found to be 44,000 psi. and the yield strength 45,900 psi. The relatively sharp break in the curve at point *A* for cold-stretched sheets is very characteristic. After unloading from *B* to *C* and applying compressive stresses from point *C* to *D*, a deformation of 0.01 per cent as low as 23,900 psi. was found, while the yield strength (0.2 per cent set) in compression was about 37,200 psi. It may be of interest to observe that in contrast to the shape of the diagram in tension (*OAB*), the compression stress-strain curve (*CDE*) is much more gradually rounded. Unloaded to point *F* and again loaded in tension, this same specimen showed an elastic limit (0.01 per cent) of 28,400 psi. at point *G* while the yield strength had again reached about 45,700 psi. on the part of the curve *GH* of this diagram. The diagram *FGH* of this same specimen after compression is very interesting, compared to the diagram *OAB* of the metal as delivered.

Figure 20 gives the results of similar tests on a specimen cut at 45 deg. to the rolling direction from sheet A. In spite of rolling and cold-stretching, the shape of the stress-strain diagram is quite different from that for a specimen at 0 deg. (Fig. 19). This diagram is rounded, having a 0.01 per cent deformation limit at 35,500 psi. (compared to 44,000 psi. in the 0 deg. direction), and a yield strength of 41,000 psi. In compression (*CDE*) the respective values were 22,600 psi. and 37,000 psi., while at a deformation of 0.5 per cent, the stresses reached about 41,800 psi. Unloaded from *E* to *F* and again stressed in tension (*FGH*), a deformation of 0.01 per cent was reached at 19,100 psi. (point *G*) and the yield strength at 34,500 psi., that is, 1,000 psi. lower than the initial elastic limit of 35,500 psi.

In Fig. 21 are shown the same kind of tests illustrating the Bauschinger-effect on specimens taken at right angles to the direction of rolling and stretching.

RÉSUMÉ OF RESULTS

The results of the preceding investigation may be summed up as follows:

1. The results obtained with a new kind of tension grips as well as with new devices for guiding specimens axially in compression have been quite satisfactory for measuring micro-deformations in tension and compression.
2. Based upon the tests it can be stated that all mechanical properties of 17S-T rolled aluminum alloy sheets depend on the angle between the test specimen and the direction of rolling.
3. In all cases a minimum of 4 to 5 per cent less ultimate resistance has been noted in the direction of 30 to 60 deg. compared with the direction of rolling.
4. The yield strength (0.2 per cent set) is highly dependent on the angle of the specimen with the rolling direction of the sheet. However, a still greater influence is found in all cases for the 0.1 per cent

limit, showing up to 20 per cent less resistance in the 75 to 90 deg. direction; for the yield point this difference is of about 15 per cent.

5. The stresses for a permanent micro-deformation of 0.01 per cent, depending on the position of the specimen in the sheet, changed in a rather impressive manner. More than 20 per cent less resistance was measured for sheets D and A and even up to 35 per cent for sheet B between 0 and 60 deg. to the direction of rolling.

6. The very pronounced directionality of these important mechanical properties for constructional purposes is primarily due to the cold stretching (1 to 2 per cent) or the levelling process during manufacturing and the orientation of the crystals in these rolled light alloy sheets.

7. Tests of the effect of preliminary micro-deformations by tension on the change of the elastic properties of 17S-T alloy sheets showed the high sensitivity of this material to compression loads. A preliminary permanent deformation by tension of only 0.1 per cent causes a change of more than 50 per cent of the 0.01 per cent limit in compression and of about 96 per cent for only 0.5 per cent permanent deformation by tension. Similar results were obtained with specimens of other sheets forming an angle of 0, 45, and 90 deg. with the direction of rolling.

8. Contrarily to other metals (copper for instance) the Young's modulus of elasticity of 17S-T alloy sheets is not influenced in a very high degree by the cold-rolling and cold-stretching process. A maximum difference of 4 to 5 per cent of the average values was measured on specimens at 45 deg.

9. Alternating tension and compression tests, made with specimens cut out in the direction of rolling as well as 45 to 90 deg. to this direction showed, after a small preliminary permanent deformation in tension, an extremely low stress limit under compression loads. The stress limit under compression of 0.01 per cent permanent deformation is, in the direction of rolling, approximately only 50 per cent of this same limit under tensile loads; after further permanent deformation of only 0.2 per cent in this same direction (compression) the tensile stress (0.01 per cent set) compared to the original value of the sheet is lowered by about 30 per cent (sheet A). Analogous results have been found in the 45- and 90-deg. directions.

10. These alternating tension and compression tests show that cold stretching of this material of only a fraction of a per cent, in the manufacturing process to produce thin flat sheets, weakens the 17-ST alloy materially. In the interest of a greater resistance of these stressed skin constructions a pre-stretching of this material of 1 to 2 per cent during the manufacturing process should be eliminated.

REFERENCES

(1) R. L. Templin and R. G. Sturm, "Some Stress-Strain Studies of Metals," *Journal of the Aeronautical Sciences*, Vol. 7, No. 5, p. 189 (1940).

(2) E. Schmid, "Kristallplastizität," F. Springer, Berlin (1935).

(3) A. E. Bryukhanow, "Development of Texture in Sheets of Brass, Aluminum and Dural at Rolling," *Journal of Technical Physics* (U.S.S.R.), Vol. 9, pp. 1754–1762 (1939).

(4) W. Lavern Howland, "Variation of the Modulus of Elasticity of Duralumin," *Journal of the Aeronautical Sciences*, Vol. 4, No. 12, October, 1937, pp. 507–509.

(5) J. Robert Fischel, "The Compressive Strength of Thin Aluminum Alloy Sheet in the Plastic Region," *Journal of the Aeronautical Sciences*, August, 1941.

DISCUSSION

Mr. H. S. Rawdon (*presented in written form*).[1]—The author should be commended for his skill and ability in testing and for the interesting data on the properties of thin aluminum alloy sheets which he has presented. However, the writer takes exception to some of the items and especially to the concluding recommendations in the summary.

The three sheets, designated as A, B, and D, on which practically all of the data were obtained, differ quite decidedly among themselves in several significant respects. No attempt has been made by the author to identify the three sheets with respect to the two lots of sheets available to him for this work. The sheets of the two lots were not identical in several respects, but the reader is unable to tie in differences in the test data, such as the variations in distribution as well as in magnitude in Fig. 13, with known initial differences in the two lots of sheets. In brief, the actual test material has not been adequately described.

The data presented by the author to demonstrate the "Bauschinger effect" serve to emphasize a basic principle well recognized by physical metallurgists. If the properties of a metal are increased in one direction, for example, in tension, the analogous properties in the other direction (in compression) are correspondingly decreased. To be specific, an increase in the tensile elastic properties of a metal obtained by cold stretching is unalterably tied in with a lowering of the compressive elastic properties. This is a *normal* characteristic for the metal and is not to be regarded necessarily as a damaging effect, although a careful designer may attempt to take account of it.

It is the writer's opinion that the recommendation contained in the concluding sentence should not be taken too seriously. The "truing-up" of sheets of various metals by *slight* stretching is common practice and such products have entered into many types of construction over a long period. Definite evidence based on service behavior of aircraft structures is needed to support and confirm such a drastic recommendation as that made by the author. Evidence has never come to the writer's attention in any of the many cases of failed aircraft examined over a long period of years which could serve to support this recommendation. Furthermore, were it possible to dispense with the stretcher-leveling of sheets, the effect would not be eliminated. Basically, it enters into the production of every part for the forming of which plastic deformation is necessary.

As a *serious* constructional hazard in aircraft service, this effect would be rated by the writer as very low in the list; it is topped by many other much more obvious potential structural hazards.

In an entirely different field of aircraft performance, surface smoothness of the assembly such as is obtained by initial slight stretching of the structural sheet used is very necessary. Stability and efficiency of an aerodynamic structure are intimately associated with character of the surface in contact with the air stream. One of the most feasible methods of obtaining the smooth surface required is to process the sheet surface by initial stretching. No effective alternate method for obtaining this necessary condition is at all obvious.

---

[1] Chief, Division of Metallurgy, National Bureau of Standards, Washington, D. C.

MR. JAMES A. MILLER[2] (*presented in written form*).—This paper serves to emphasize the desirability of obtaining accurate compressive stress-strain curves of sheet metal especially when the sheet has been cold-worked after heat treatment.

We at the National Bureau of Standards have been interested for a number of years in the testing of sheet metal in end compression and have devised a number of methods for providing lateral support to prevent premature buckling, for example the pack method of C. S. Aitchison and L. B. Tuckerman described in National Advisory Committee for Aeronautics Report No. 649. For this reason we are interested in the details of the device shown, particularly in the nature of its contact with the specimen and in the means used to reduce friction. We note that the stress-strain records shown appear much less smooth for compression than for tension. We would like to know whether results obtained with these devices have been compared with those obtained on specimens from the same sheet by other methods such as the pack method or the single-thickness method, developed by W. P. Montgomery and R. L. Templin, in which the lateral support is provided by rollers. We would be interested to know if Mr. Welter has made any tests with gages mounted on the edge faces of the specimen to determine the degree of uniformity of the stress distribution.

About two years ago, Mr. C. S. Aitchison and I made some compressive tests of 0.032-in. 24S-RT sheet as part of an investigation for the Bureau of Aeronautics, Navy Department. In these tests the lateral support against premature buckling was provided by improvised solid brass guides with a coating of graphite grease between each guide and the specimen. The results obtained were in good agreement with those obtained on specimens from the same sheet by the single-thickness method. These tests pointed the way to the development of a simple fixture and a procedure for making compressive tests of thin sheet which I am taking this opportunity to describe. The fixture has been in use for several months. With it we have been able to obtain the stress-strain curve beyond the 0.2 per cent offset yield strength for sheet thinner than 0.006 in. with a yield strength of about 160,000 psi. and for 0.020-in. sheet with a yield strength as high as 240,000 psi.

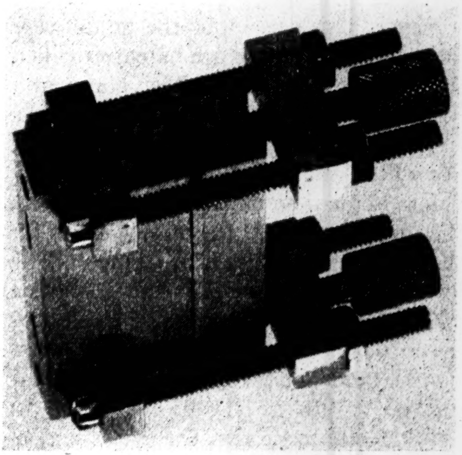


FIG. 1.—Fixture for Compressive Tests of Thin Sheet Metal.

The fixture is shown with a specimen in the accompanying Fig. 1. It was designed for a specimen $\frac{1}{2}$ in. wide with a 1-in. gage length. It consists of two hardened tool steel guides and two adjustable clamps. It can be taken apart quickly for cleaning the guides by loosening the set screws holding the clamps in place. One guide is self-adjusting for linear variation in the thickness of a specimen.

---

[2] Assistant Physicist, National Bureau of Standards, Washington, D. C.

The guides are rectangular blocks of hardened tool steel nominally 0.375 by 0.46 by 2.20 in. One of the 0.46 by 2.20-in. surfaces of each is a guiding surface. A piece of the same tool steel which had been machined to space and hold the clamps was attached to one of the guides on the side opposite the guiding surface. This was done after the guide was hardened and ground nearly to size. This piece and the guide were finished together and are hereafter called the compound guide. The compound guide serves for the alignment of the specimen in the testing machine. The other, the simple guide, was machined, before hardening, on the surface opposite the guiding surface to provide seats for the adjusting screws of the clamps. The lower is a conical seat and the upper is a 120-deg. groove. The simple guide was made 0.002 in. shorter than the compound guide and the conical seat was located so that the lower end would be about 0.002 in. above the lower end of the compound guide. This prevents small changes in the seating of the clamps from causing the lower end of the simple guide to interfere with the alignment of the specimen.

The holes for the 8-32 tension screws were drilled and tapped while the cross-bars for each clamp were clamped together. Rigidity is obtained by tightening the head of each tension screw against the smaller cross-bar and then tightening the locknuts against the larger cross-bar. The 10-32 adjusting screws have a travel of over $\frac{1}{8}$ in. The spacing of the cross-bars can be varied in steps of $\frac{1}{32}$ in. by removing one of the tension screws from the large cross-bar, turning the large cross-bar to the desired location, and resetting the tension screws.

Ordinarily, the specimens for test in the above fixture are $\frac{1}{2}$ in. wide and $2\frac{1}{4}$ in. long. Thus they have the same cross-sectional area as standard tension test specimens from the same sheet. For specimens less than 0.020 in. thick the length should be slightly less. For specimens less than 0.010 in. thick the length should be just enough to provide clearance of 0.002 or 0.003 in. between the top of the guides and the bearing block when the yield strain is reached. For specimens thinner than 0.010 in. the width should be reduced to 0.48 in.

The edges of the specimens were finished by grinding. Several specimens were ground at one time. They were held in a vise which could be turned end for end to permit finishing both ends without removing the specimens. The resulting specimens were satisfactory for test between hardened steel bearing blocks which had been set parallel at the beginning of a series of tests.

Before a specimen was placed in the test fixture the burrs were removed from the edges. Care was taken not to damage the end surfaces of the specimen. The broad surfaces of the specimen were rubbed lightly with a hardened steel scraper to remove small particles of the material projecting above the surfaces. Finally the ends of the specimen were lapped superficially on a roughly ground hardened steel block to remove any material that might prevent uniform contact with the bearing blocks.

The specimen was then cleaned and covered on both sides with a thin coat of lubricant (Texaco Marfak No. 3) and inserted between the guides in the fixture. The adjusting screws were tightened and retightened with intervening sliding of the specimen until the guides did not slide axially under their own weight but did slide smoothly under an additional weight of 1 lb. or less. After a little practice an operator can tell by feel when the desired condition is obtained. When the sliding is not smooth but jerky there may be foreign matter between a guide and the specimen or, in the case of newly finished guiding surfaces, a burr at an edge which scratches the specimen. When ordinary care is taken in cleaning and greasing the specimen several specimens can be tested between each cleaning of the guides.

The specimen was then centered laterally in the guides by eye. The lower end was set even with the lower end of the compound guide and the lubricant was wiped from the ends. The specimen was then aligned in the fixture by pressing the specimen and compound guide against a surface plate.

The specimen was centered in the testing machine and an initial load of about 20 lb. was applied. Tuckerman 1-in. strain gages were then attached to the edge faces of the specimen. After the yield strength was reached the gages were removed. Before reducing the load the guides were moved with the fingers to show the absence of appreciable friction.

Numerous tests have been made to compare the results obtained with the fixture with those obtained by other methods. Figure 2 shows stress-deviation graphs obtained from pack tests and tests with this fixture. These indicate close agreement between the stress-strain curves obtained by the two methods.

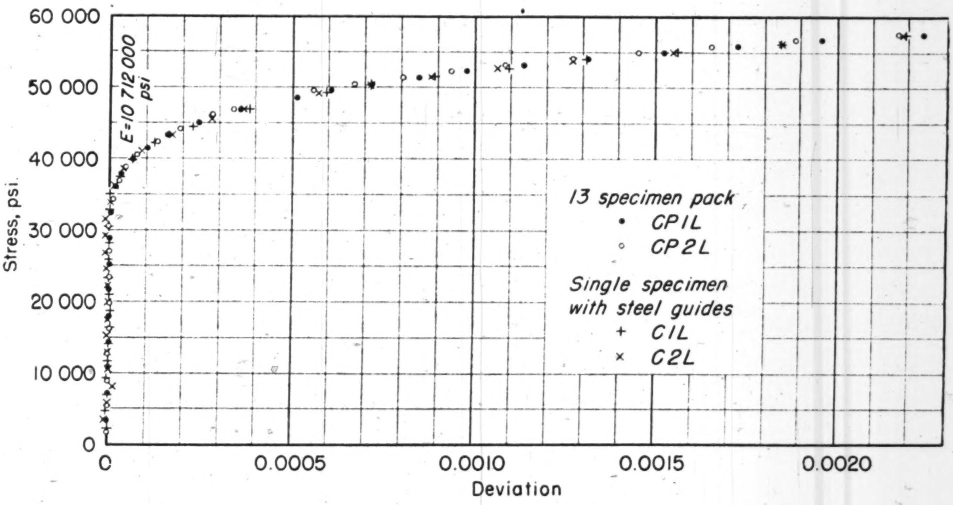


FIG. 2.—Compressive Tests on Aluminum Alloy 24S-RT 0.032-in. Sheet in Direction of Rolling.

We have made no tests in both tension and compression on the same specimen. However the method is especially suitable for such tests.

The author wishes to thank the Bureau of Aeronautics for permission to present this discussion.

MR. R. L. TEMPLIN.[3]—The author has presented some very interesting data relative to 17S-T aluminum alloy sheet. In his experiments to obtain the data he has demonstrated the necessity for using testing apparatus that will stress the test specimens both axially and uniformly. The test data submitted indicate that this requirement of good testing technique has been realized within satisfactory limits. It would appear from the photographs of the apparatus used (Figs. 4, 5, 6, and 7) that rather extensive manipulation of the tension test grips and compression device is necessary in the case of each test. For example, in the tension grips it would seem necessary to tighten, adjust, and subsequently release 16 separate cap screws for each tension test. In the case of the compression device, it appears necessary to adjust and release or remove 5 to 9 machine screws in testing each specimen. The time involved in making such adjustments would appear to preclude the consideration of the use of such testing apparatus in the thousands of routine inspection tests now made commercially in controlling the quality of aluminum sheet. In actual practice under present conditions, tension tests of aluminum sheet, including the use of stress-strain apparatus shown in Fig. 4 by the author, are being made at the rate of 15 or more per testing machine hour using one operator per machine. The grips used for such tests, however, are the type indicated by Fig. 16 of A.S.T.M. Standard Methods of Tension Testing of Metallic Materials (E 8 - 42).[4] The unsuitability of what the author terms "the usual technique" in making tension tests of thin sheet metals has been brought to this Society's attention on a number of previous occasions. In the case of aluminum sheet, the point was particularly emphasized by the writer in 1927.[5]

---

[3] Assistant Director of Research and Chief Engineer of Tests, Aluminum Company of America, New Kensington, Pa.

Commercial apparatus is available today in this country for use in making compression tests of thin sheet metal specimens, that apparently accomplishes all that the author's compression testing device does with much less manipulation involved for each test.

The author's results show very nicely the variations in stress values with respect to different micro-deformations, for the material investigated. He has expressed the opinion that these variations are very important in the case of the buckling stress of panels such as used in aircraft. Irrespective of the validity of the opinion expressed, it can be pointed out that the fabrication procedures used in making aircraft of aluminum sheet undoubtedly result in micro-deformations that change the stress-strain relationships of the material as much as the amounts found by the author and attributed to rolling and flattening by stretching of the sheet. Certainly the aircraft manufacturer requires flat sheet as evidenced by the specification requirements governing flatness. Furthermore, under service conditions many parts of aircraft, including the panels mentioned, undergo micro-deformations that affect the stress-strain relationships of the aluminum sheet in the stress range below the yield strength, apparently without any deleterious results in so far as the performance of the structure is concerned. These micro-deformations, in all probability, are a real benefit to the structure as they often assist in accomplishing a stress adjustment which is desirable from the standpoint of the fatigue life of the structure.

In view of these points it is very difficult to accept the author's recommendation that the manufacturers of aluminum sheet should eliminate the stretching of 1 or 2 per cent used for flattening the product. A corollary of this conclusion would be that the aircraft maker should not use the stretch forming process nor do any cold forming of aluminum sheet where it is to be used as strength panels.

---

[4] 1942 Book of A.S.T.M. Standards, Part I, p. 904.

[5] R. L. Templin, "Methods for Determining the Tensile Properties of Thin Sheet Metals," *Proceedings*, Am. Soc. Testing Mats., Vol. 27, Part II, p. 235 (1927).

Many thousands of very successful aircraft have been made from stretch flattened aluminum sheet which also has been stretched or otherwise formed by the aircraft maker. It does not appear that the cold forming operations used by the aircraft makers could be eliminated, in order to avoid effects of the micro-deformations on the stress-strain relationships of aluminum sheet. Even though such were possible, there is no evidence showing that the results obtained would justify the difficulties involved.

In conclusion the observation might be made that the variations in the aluminum sheet found by the author probably are appreciably less than variations introduced by the fabricators who use aluminum sheet and those introduced by the service conditions of structures made from aluminum sheet, particularly aircraft.

MR. G. WELTER[6] (*Author's closure, by letter*).—I have read with great interest the discussions by Messrs. J. E. Miller, H. S. Rawdon, and R. L. Templin and am submitting the following comments on some points of this discussion.

Concerning the testing apparatus, it may be mentioned that the tension grips, as well as the compression device, have been projected solely for research purposes; therefore stressing the specimen axially and uniformly has been considered as being of greater importance than any easy and rapid manipulation of these devices. The heads of the flat specimens are laterally guided inside these divided steel sheaths according to Figs. 4 and 5 and are fixed by friction on hardened steel faces of about $\frac{3}{4}$ by $1\frac{1}{2}$ in. with sharp teeth, so that only a fairly low pressure is necessary to prevent sliding of the specimen in the sheath. The testing practice showed that the manipulation of four nuts was sufficient to fix the specimen securely in the sheath; only two of these had to be tightened by a wrench while the other two, which may be of the butterfly-type, can be tightened by hand. During this investigation, each complete diagram (micro-deformation and stress-strain diagrams), according to Fig. 3, could be recorded with the low speed of the recorder in about 6 to 8 min. and the additional time for adaptation of the specimen in the sheath took only a small percentage of this time.

It is hardly necessary to point out that the grips for sheet material shown in Fig. 16 of A.S.T.M. Standard Methods of Tension Testing of Metallic Materials (E 8 – 42)[7] are not, as stated in Section 17 (*c*), "self-adjusting" grips. Due to the spherical bearing in the cross-head of the testing machine, which unfortunately is not self-aligning, these grips, devised for sheet specimens, work under load not much more satisfactorily than the usual type of wedge grips. It is evident that the breaking strength of brittle material and the elastic limit of all other materials may be seriously penalized by these and similar so-called self-adjusting grips; under increasing loads they cannot compensate the constant changes in the non-translational movement of the cross-heads of the testing machines.

A commercial apparatus available for use in making compression tests of thin sheet metal specimens which permits an automatic recording of the elastic and micro-plastic deformations of the specimens, is not known to me. Besides the "pack method," the only device which I have seen for testing thin single sheets in compression is the "Montgomery" type, manufactured by Baldwin Southwark. It does not seem to me that with this commercial apparatus, less manipulation is necessary or that it works faster than the device shown in Figs. 6 and 7. With this device, the time required for each compression test including the stress-strain diagrams shown in Fig. 8, is about double that for the tension tests. By some slight changes of the sheath using 3 to 4 butterfly-nuts, this time of manipulation without any doubt, can be appreciably reduced.

---

[6] Professor of Applied Mechanics, Ecole Polytechnique, University of Montreal, Montreal, Canada.

[7] 1942 Book of A.S.T.M. Standards, Part I, p. 904.

The rigid steel sheath for preventing buckling of the thin specimens is adjusted to the thickness of the specimen so that the sheath can slide easily by its own weight; a coating of graphited heavy oil is used between the sheath and the specimens.

In my opinion, the compressing jig used in testing single sheet specimens in compression, described in N.A.C.A. technical note No. 819, is not ideal for compression tests; in fact the small lateral roller supports on each side of the specimen, placed about $\frac{1}{16}$ in. apart, do not keep the specimen completely straight during the test; under load the specimen takes a sinusoidal form. Besides this, reducing the surface of the supporting faces of the specimen by the rollers to a series of horizontal contact lines does not seem to be the correct procedure; in order to lower the friction between the specimens and the sheath to a minimum, it is necessary that the supporting surfaces be as large as possible. Besides this, it does not seem likely that the rollers under load will turn when sliding the specimen in the device; this means that, instead of an apparent decrease of friction by the rollers, a serious increase takes place. Incidentally, I wonder how many screws this device is provided with and how many have to be manipulated to adjust the specimen and the device to the testing machine; furthermore, a weak point of this device seems to be the introduction and diffusion of the loads from the loading tables of the machine to both ends of these small thin flat specimens.

Concerning the variations in basic stress values with respect to different micro-deformations of thin aluminum alloy sheets, which may become fairly high, I am under the impression that the mechanical anisotropy of the sheets is most important; especially in this case where the buckling stress of panels used in aircraft is involved. As quoted in my paper, changes of 80 to 90 per cent in the 0.01 per cent limit (of permanent deformation) in compression compared to tension have been measured. However, much higher changes may be expected if results are considered for the 0.001 per cent limit, which, after preliminary deformations of 0.5 to 1 per cent in tension, may be as low as 15,000 psi. in compression (19,100 psi. have already been measured at the 0.01 per cent limit in the 45 deg. direction). Due to the commercial thickness tolerances for sheets, a cross-section of 0.18 sq. in. is possible in a 0.032-in. panel (6 in. wide). Consequently at an average buckling load of 2200 lb. on these panels, a stress of more than 12,000 psi. can easily be reached. If we furthermore take into consideration that the compression loads are not regularly distributed over the whole width of the panel when reaching the maximum buckling load, an influence of the anisotropy of the sheets does not at all seem to be out of question, especially in the restrained part of the panel. Based on special test series, carried out from this point of view, I must say that I am not as much afraid of small differences in eccentricity of the panels than of the very serious mechanical anisotropy of the cold-stretched sheet material itself.

If the fabrication procedure used by the aircraft manufacturers is changing appreciably the stress-strain relation of the material designed for an important element, then without any doubt it will be useful to find out what the consequences of these changes may be in the behavior of the structure in service.

The successful use of "cold-stretched" duralumin sheets in an aircraft panel means that the structure is heavy enough to resist any failure, but it does not mean that the panel is as light as it might be so as to reduce the superfluous dead load to a minimum. For panels used in aircraft, the variations introduced by the fabricator are low as the panels are only slightly bent (not stretched) to adapt them to the monocoque structures. So it is not easy to understand that due to cold stretching of the sheets by the manufacturer, the very pronounced changes in the 0.01 per cent limit between tension and compression, according to Figs. 14 and 15, may be introduced through the manipulation of the panels by the fabricators or even the service conditions of panels. In any event these test results seem to me so important for the designer of monocoque constructions and in general for all light alloy constructions that the research about this point and other materials will be continued.

The discussion by Mr. Rawdon principally takes exception to the same point as that discussed by Mr. Templin and a part of these comments have been discussed above.

Here too, it seems to me that an effect which can change as much as 80 to 90 per cent the vital properties of a panel on which the design is predominantly based is a serious constructional hazard in aircraft service and can hardly be surpassed by many other much more important ones, as Mr. Rawdon states. It is rather difficult to understand what Mr. Rawdon means by tying in differences in the test data of Fig. 13 with known initial differences in the two lots of sheets. The sheets which were tested were 0.032-in. thick 17S-T (duralumin) of normal composition and heat treatment. The two lots differed only in lengths and widths of the sheets; evidently these factors cannot have a marked influence on the ultimate strength of the specimen. Figure 13, in which are represented the changes of ultimate strength of the specimens with the direction of rolling is, according to my opinion, the least interesting one for the designer and any speculation about the question why one of the sheets (*A*) has in the 45-deg. direction a variation of the ultimate load of -2.0 per cent, sheet *D* a variation of about -1.2 per cent, and sheet *B* less than -1 per cent, seems to me of no special interest for the use of these sheets in monocoque constructions. Evidently of much greater importance, especially to the designer, is Fig. 14 (as well as Fig. 15) representing the changes of stress (0.01 per cent permanent deformation) in function of preliminary permanent deformation up to 0.5 per cent. Also Figs. 18 to 21 show very clearly how the thin aluminum alloy sheets under tension and compression are working with regard to their micro-deformation, their elastic limit or the yield point. It is these basic characteristics which are of fundamental importance to the designer of panels, or, in general, for monocoque aircraft constructions as well as for other structural materials. For purposes of design these characteristics describe much more adequately the actual test material than any results about ultimate loads, total elongation, reduction of area, etc.

The constructive contribution of Mr. J. A. Miller to these questions is an interesting one and it shows that devices to obtain accurate stress-strain curves of thin specimens, as described in my paper, are in good agreement with results of the earlier "pack method." Tests with gages mounted on the edge faces of the specimen have not been repeated here because they represent an earlier stage of the development of these devices. The uniformity of the stress distribution over the width of the specimen need not be controlled if the stresses are introduced completely axially into the specimen. This can be easily guaranteed by using two small rollers placed perpendicular to the specimen and applied in the axis of the sheath on the top and bottom end of the transverse members *G* and *G'*, according to Fig. 6 of my paper.

SHORT-TIME TESTS OF SOLDERS AND SOLDERED JOINTS

By J. A. Kies[1] and W. F. Roeser[1]

Synopsis

Many of the compositions of low-tin solders included in various specifications differ only in small percentages of elements such as antimony, bismuth, copper, and silver. Since short-time tests are frequently relied on to prove the value or importance of such additions, it is essential to establish procedures which are simple and will yield results which are both reproducible and easily interpreted. The scarf joint was investigated and found to be advantageous for the purpose. Results are presented which indicate the effects of speed of pulling, rate of loading, time of supporting the load, temperature, and pretinning on the shear strengths of soldered joints. Such data are considered useful in setting up standard procedures for short-time tests of solders and soldered joints. Shear strengths for one set of conditions are given for joints made with thirteen solders. Of these, six correspond in composition with A.S.T.M. solders Nos. 11, 12, 13, 14, 15, and 16 included in Emergency Alternate Provisions in Tentative Specifications for Soft-Solder Metal (B 32 – 40 T) issued January 5, 1943;[2] four corresponded with solders B, D, E, and G of Federal Specification for Solder, Tin-Lead (QQ-S-571a) dated February 11, 1942; and one corresponded with solders R and M of Emergency Alternate Federal Specification for Solder (E-QQ-S-571a), dated September 29, 1942. Nine of the solders corresponded in composition with solders E01, E02, E03, E04, E05, E06, E07, 2A, and 6A in 1943 S.A.E. specifications. In addition a commercial 50–50 tin-lead solder was investigated.

Spreading tests of ten solders, using a eutectic mixture of zinc and ammonium chlorides on copper and iron were made. Spreading tests of A.S.T.M. solder No. 16 and 50–50 solder were also made using 14 different fluxes on copper and 14 fluxes on iron. Fifteen fluxes were included in the investigation.

Since the prospect of an acute shortage of tin continues, conservation measures must be continued. Although the percentage of tin that may be used in solders for various purposes has been limited by the War Production Board, tin is still a major constituent of solders used for general purposes. Numerous new compositions of low-tin solders have been proposed as substitutes for the conventional pre-war 50–50 lead-tin solder and have been included in various specifications for solders.

Many of the proposed compositions of low-tin solders differ only in small percentages of especially added elements such as antimony, bismuth, and silver. Few data on the effects or importance of these added elements are available. At the present time there are no generally accepted test methods for determining the effects of elements added to solders or for providing data which would be of material aid in the selection of the most suitable solder for a specific purpose.

---

[1] Associate Metallurgist, and Principal Metallurgist, respectively, National Bureau of Standards, Washington, D. C.

[2] 1942 Book of A.S.T.M. Standards, Part I, p. 1411.

In addition to such factors as soldering temperature, freezing range, spreading or "tinning" ability, etc., which are important in determining whether a solder is suitable for a given application, adequate strength of the soldered joint is essential. A number of papers have been published giving the results of tests of joints made with different solders, but in many cases the results are of questionable utility because (*a*) all of the many factors affecting the results obtained were not controlled or reported, or (*b*) the types of joints used were such that the results obtained depended more upon the type of joint and method of loading than upon the solder.

The factors influencing the results obtained from testing soldered joints were discussed in a previous paper (**1**).[3] The purposes of this paper are (*a*) to discuss these factors further, (*b*) to present data showing the effects of the various factors, (*c*) to present the results of tests with different low-tin solders with types of joints in which the disturbing factors are eliminated or most easily controlled, and (*d*) to present results of spreading or "tinning" tests with the different solders under different conditions.

In devising methods of test it is advisable to simulate service conditions as closely as practicable. However, solder is used for making such a large variety of joints that no one type can be used to represent all service conditions. Soldered joints in service are subjected to practically all types and combinations of stress. In most tests of soldered joints, attempts have been made to measure the shear strength of the joint and to express the results in pounds per square inch. In order to accomplish this and to obtain results which depend only on the solder, it is necessary that rupture be confined to the solder and that distortion by bending or other deformation in the basis metal be minimized. Ease and reproducibility of soldering as well as freedom from accumulations of solder in corners, fillets, etc., are important matters.

Numerous data on the strength of soldered lap joints (**1**, **2**, **3**), plug and sleeve joints (**4**, **5**, **6**), butt joints between rods (**7**, **8**), and the Chadwick joint (**9**, **10**) have been published. In spite of certain obvious advantages of the scarf joint and the fact that it is commonly used in service, there are apparently no published results of tests made with this type of joint. In the present work, the possibilities and merits of the scarf joint for test purposes were investigated. Tests of various solders were made with this and several other types of joint for the purpose of comparing the results obtained with different solders and different types of joint.

TABLE I.—DESIGNATIONS OF SOLDERS.

A.S.T.M.	Federal	S.A.E.
11	M	E01
12	..	E02
13	..	E03
14	..	E04
15	..	E05
..	..	E06
16	R	E07
..	B	2A
..	D	..
..	E	..
..	G	..
..	..	6A

MATERIALS

Solders:

Thirteen solders were investigated. Twelve of these corresponded in composition with solders whose designations, according to current A.S.T.M., S.A.E., and Federal specifications, are as given in Table I.

---

[3] The boldface numbers in parentheses refer to the reports and papers appearing in the list of references appended to this paper, see p. 706.

Solders Nos. 11, 12, 13, 14, 15, and 16 are included in the A.S.T.M. Emergency Alternate Specifications EA-B32a.[2] The 1943 S.A.E. Specification, in which solders E01, E02, E03, E04, E05, E06, and E07 are included, is entitled "S.A.E. Non-Ferrous Metals, Emergency Alternate Specifications." Solders 2A and 6A are included in the 1943 list of S.A.E. standard solders. Solders B, D, E, and G are included in Federal Specification for Solder, Tin-Lead (QQ-S-571a), dated February 11, 1942, and solders R and M are included in Emergency Alternate Federal Specification for Solder; Tin-Lead (E-QQ-S-571a), dated September 29, 1942.

In addition, a commercial 50–50 tin-lead solder was included in the investigation to serve as a standard for comparisons. All of the solders are listed in Table II together with data on composition, freezing range, and density.

Hereafter in this paper the A.S.T.M. designations will be used wherever possible. Federal designations will be used rather than S.A.E designations wherever possible, and the S.A.E. designation will be used in the two cases to which neither an A.S.T.M. nor a Federal designation can be applied.

Materials Joined:

Copper.—Single lap and scarf joints with a scarf angle of 14½ deg. were made between copper strips having dimensions of 1 by 0.096 by 6 in. These were tested in tension. Butt joints between copper tubes having an outer diameter of 1.125 in. and a wall-thickness of 0.065 in. were tested in torsion.

TABLE II.—COMPOSITIONS, MELTING RANGES, AND DENSITIES OF SOLDERS INVESTIGATED.

Solder	Composition by Weight, per cent						Melting Range[a]						Density, g. per cu. cm.[b]
	Tin	Antimony	Copper	Bismuth	Silver	Lead	Solidus Temperature		Temperature of Maximum Heat Evolution		Liquidus Temperature		
							deg. Cent.	deg. Fahr.	deg. Cent.	deg. Fahr.	deg. Cent.	deg. Fahr.	
50-50[c]	....	....	....	....	....	....	182	360	...	...	217	423	8.85
B	40	0.30	0.06	0.20	....	remainder	181	358	182	360	250	482	9.35
D	35	1.00	0.06	0.20	....	remainder	181	358	184	363	256	493	9.50
E	30	0.60	0.10	0.20	....	remainder	181	358	183	361	261	502	9.64
G	20	0.56	0.10	0.20	....	remainder	181	358	183	361	282	540	10.16
11	20	0.40	0.06	0.56	1.25	remainder	176	349	178	352	273	523	10.16
12	20	0.33	....	5.0	1.25	remainder	159	318	172	342	253	487	10.16
6A	15	0.33	....	....	....	remainder	183	361	186	367	285	545	10.44
13	15	0.33	....	0.6	1.25	remainder	176	349	177	351	276	529	10.44
14	15	0.33	....	5.0	1.25	remainder	159	318	172	342	262	504	10.42
15	9.97	0.33	....	0.6	1.50	remainder	175	347	287	549	289	552	10.71
EC6	2.99	0.33	....	....	2.24	remainder	275	527	305	581	306	583	11.10
16	....	0.33	....	....	2.49	remainder	300	572	302	576	303	577	11.29

[a] Determined by A. I. Dahl, Associate Physicist, National Bureau of Standards.
[b] Determined by Miss M. G. Blair, Junior Physicist, National Bureau of Standards.
[c] A commercial product.

Brass.—Single lap joints in yellow brass strips, 1 by 0.125 by 6 in., were made for tension tests. Scarf joints with eight different scarf angles ranging from 4 deg. to 71½ deg. were prepared with similar brass strips. Plug and sleeve joints were made between ½-in. diameter plugs and sleeves having a 0.125-in. wall thickness. All of the above were tested in tension.

Butt joints between brass tubes having an outer diameter of 1.30 in. and a wall thickness of 0.063 in. were prepared for shear tests in torsion.

Steel.—Scarf joints with 4- and 14½-

deg. angles of scarf were made between strips of cold rolled steel 1 by 0.125 by 6 in. in size for tension tests.

Butt joints between steel tubes having an outer diameter of 1.25 in. and a wall thickness of 0.063 in. were prepared for shear tests in torsion.

Materials for Spreading Tests:

Fifteen fluxes, including some proprietary products, were tested. The fluxes are listed in Table III according to approximate composition. Spreading tests were made on sheet copper 0.022 in. thick and on sheet iron 0.035 in. thick.

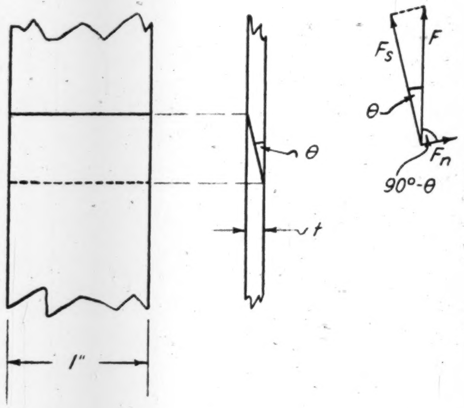


FIG. 1.—The Scarf Joint.

θ is the scarf angle, F is the tensile load on the specimen, F_s is the component of F resolved in the direction of shearing in the solder, and F_n is the component of F normal to the surfaces joined.

PROCEDURES AND RESULTS

Scarf Joint:

A diagram of the scarf joint is shown in Fig. 1. The scarf angle and the relation between the shearing and normal components of the load are given in the figure.

The shear strength of the scarf joint was calculated from the formula

$$S = \frac{F \sin \theta \cdot \cos \theta}{t}$$

where:

S = the shear stress in the plane of the joint and in the direction of shearing,
F = the maximum load during the test,
θ = the scarf angle, and
t = the thickness of the strips joined.

All values reported for the strength of joints are the averages of at least four independent determinations.

Two outstanding advantages of the scarf joint are its freedom from eccentricity of loading and the absence of a sudden change of section. Experience soon demonstrated other important advantages: (*a*) the joint was easily prepared; (*b*) the solder thickness could be regulated by fine spacer wires; (*c*) the fracture area was regular and sharply outlined; (*d*) moderately excessive quan-

TABLE III.—APPROXIMATE COMPOSITIONS AND ACIDITY OF FLUXES.

Flux	$ZnCl_2$, per cent	NH_4Cl, per cent	Other	Acidity	Vehicle
A	45	5.3	3.7 per cent $SnCl_2$	Strong	Water
B[a]	35.5	14.5	....	Slight	Water
C	21	....	Resinous water	pH 5	Petrolatum
D	47	1	Water & alcohol	pH 4	Oil
E	87	9	....	pH 5	"Dry salts"
F	54	1.7	Organic	pH 3	Water
G	62	8.6	....	pH 3	Water
H	31	6	15 per cent alcohol	pH 3	Water
I[a]	50				Water
J	23	3.6	Organic + 13% HCl	Very strong	Water
K	....	....	Phosphate	pH 4	Probably mineral oil
L	....	Not analyzed		Not analyzed	
M	....	....	Phosphates	pH 6	Water
N[a]	....	....	Rosin	....	Alcohol
O[a]	Trihydroxyethylamine		Stearate	....	None

[a] Not proprietary.

tities of solder did not alter the fracture area, that is, there were no fillets; (*e*) the scarf angle could be regulated so as practically to eliminate the effects of the component of tensile stress normal to the joint; and (*f*) the test results in terms of shear strength were consistent with the results obtained with other satisfactory types of joint.

Soldering of scarf joints was accomplished by laying the strips together horizontally and flowing the solder into one end of the lap. Brass spacer wires 0.004 in. in diameter were inserted in each joint. All joints were raised to 50 C. above the liquidus point of the solder. In the first experiments to determine the effect of scarf angle, the joints were tested at room temperature. The specimens were tested in a tension testing machine; the speed of the moving crosshead was 0.06 in. per min. The same procedure was used in testing other types of joint for comparisons.

To determine the optimum scarf angle for use in subsequent tests, specimens were prepared with angles (eight in number) ranging from 4 deg. to 71½ deg. The shear strengths for joints in brass made with solder No. 13 are given in Fig. 2. The tangent of the scarf angle was plotted because it gives the ratio of the normal stress on the joint to the shear stress in the direction of shearing. The maximum shear strength was obtained when the normal stress was between 0.2 and 0.4 times the resolved shear stress. For a scarf angle of 4 deg. (tan $\theta \cong 0.07$) fracture occurred in the brass, and thus prevented a determination of the shear strength of the joint. Joints in steel with a 4-deg. scarf angle gave satisfactory results which were practically the same as those obtained for a 14½-deg. angle (tan $\theta \cong 0.26$). It was therefore decided that 14½ deg. was a satisfactory scarf angle for brass and steel. Other angles within a few degrees of this would have been equally satisfactory.

Three types of joint, made with 50–50 solder on brass, steel, and copper, were tested at room temperature. Ten-

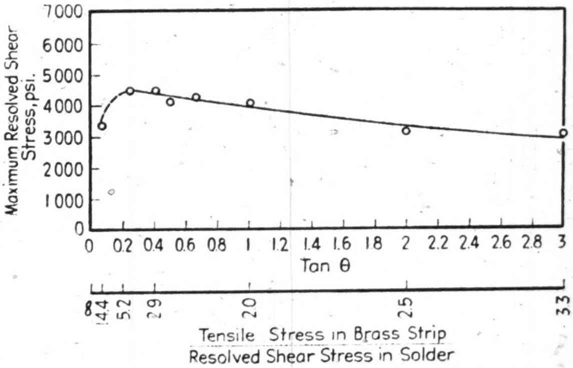


FIG. 2.—The Relationship Between Maximum Shear Stress and the Scarf Angle.
Tests at room temperature, 0.06 in. per min., solder No. 13 on brass.

TABLE IV.—COMPARISON OF SHEAR STRENGTHS OF DIFFERENT JOINTS.
50-50 Solder, Room Temperature.

Metal Joined	Shear Strengths, psi.		
	Torsion Tests, Tubes	Scarf Joints 14 ½ deg. angle	Single Lap Joints, Fillets Removed
Brass	4830	5370	4200
Steel	4350	5000	4790
Copper	4310	4180	3300

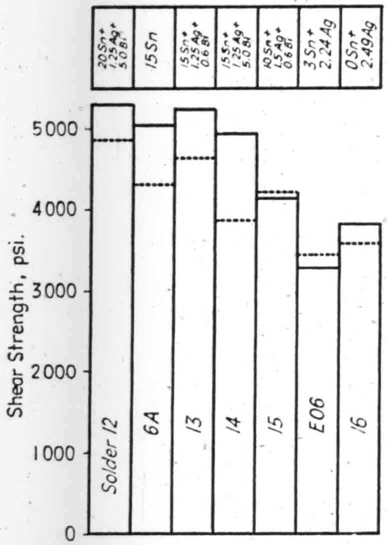


FIG. 3.—Shear Strengths of Plug and Sleeve Joints in Brass Made with Various Solders.

Room temperature, speed of crosshead = 0.06 in. per min. Dotted and solid lines represent the strengths obtained with first and second solderings, respectively. Only those elements present in excess of 0.5 per cent are listed.

sion tests were made with a crosshead speed of 0.06 in. per min. The torsion testing machine was operated at a uniform speed so chosen that the time necessary to produce failure of the joint was about the same as in the tension tests. The thickness of the solder film was substantially 0.004 in. for each type of joint. The results are given in Table IV. According to the results, the strengths obtained with the 14½ deg. scarf joint compared favorably with those obtained with butt joints in thin-walled tubes tested in torsional shear. The strengths obtained with the scarf joint were uniformly higher than those obtained with the single lap joint.

Shear strengths of plug and sleeve joints made with seven solders were determined for comparison with the strengths obtained with scarf joints with the same solders. The two sets of results are given in Figs. 3 and 4, respec-

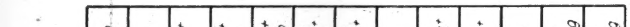


FIG. 4.—Shear Strengths of Scarf Joints in Brass.

Brass strips 0.125 in. thick, angle of scarf = 14½ deg. Dotted and solid lines represent the strengths obtained with first and second solderings, respectively. Speed of crosshead = 0.06 in. per min. Room temperature. Only those elements present in excess of 0.5 per cent are listed.

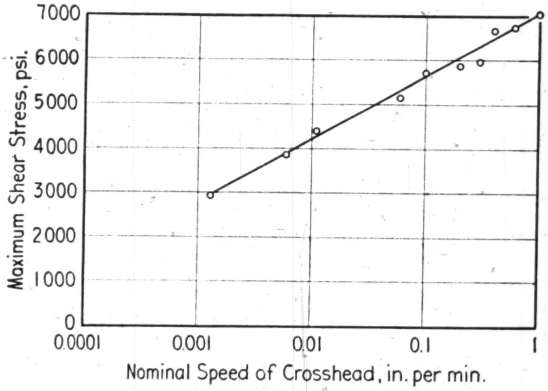


FIG. 5.—The Effect of Pulling Speed on the Shear Strength of Soldered Scarf Joints.

Tests at room temperature, 50-50 solder on steel strip. The joint surfaces were pretinned with 50-50 solder. Scarf angle = 14½ deg.

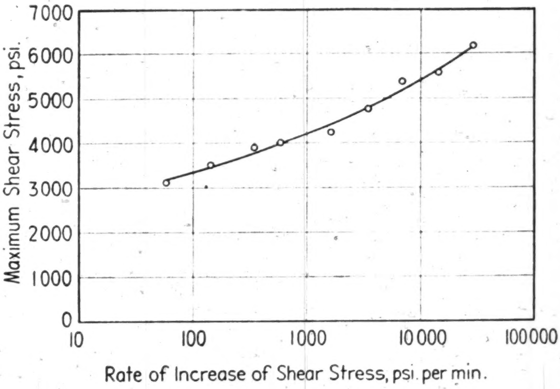


FIG. 6.—The Effect of Rate of Loading on the Shear Strength of Joints Soldered with 50-50.

Tests at room temperature. The joint surfaces were pretinned with 50-50 solder. Scarf angle = 14½ deg.

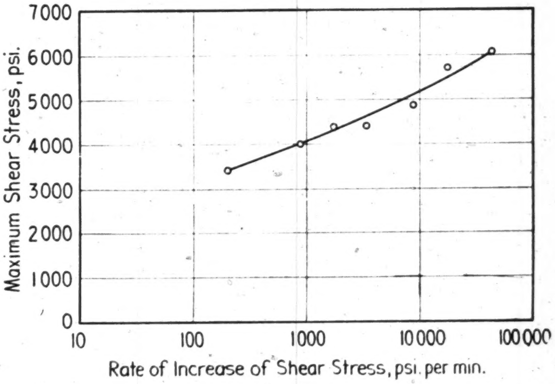


FIG. 7.—The Effect of Rate of Loading on the Shear Strength of Joints Soldered with Solder E (30 per cent tin).

Tests at room temperature. The joint surfaces were pretinned with solder E. Scarf angle = 14½ deg.

tively. It should be noted that the shear strengths were practically the same for the two types of joint.

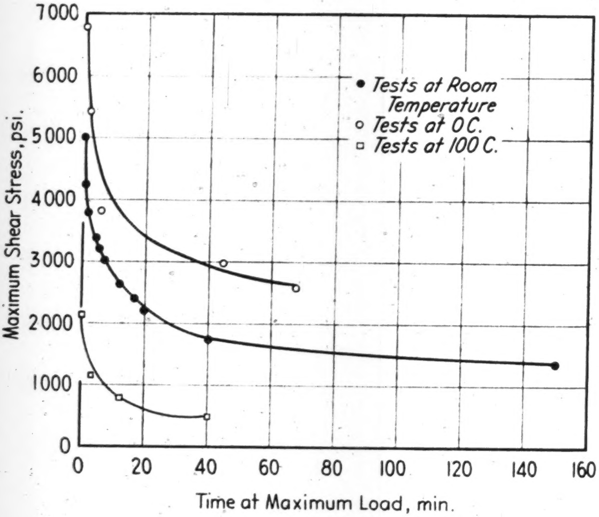


FIG. 8.—Effects of Time and Temperature on the Strength of Scarf Joints Made with 50–50 Solder. The crosshead was moved 0.06 in. per min. until the maximum load was reached.

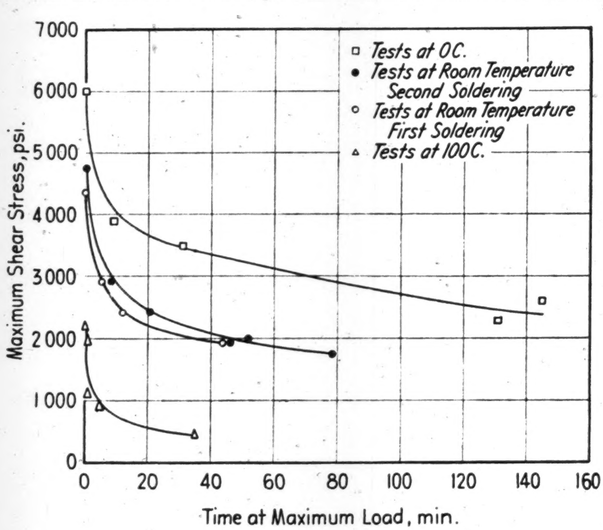


FIG. 9.—Effects of Time and Temperature on the Strength of Scarf Joints Made with Solder E. The crosshead was moved 0.06 in. per min. until the maximum load was reached.

In view of the convenience and reliability of the scarf joint, it was decided to use it in the study of the factors influencing the strength of soldered joints and in evaluating the short-time shear strengths of the 13 solders used.

Factors Influencing the Strengths of Soldered Joints:

Few data are available on the various factors which influence the short-time strength of soldered joints. It has been shown (1, 6) that the optimum film thickness for soft solders is about 0.002 to 0.005 in. Other factors were discussed but few data were given for short-time tests. The following experiments were conducted to supply such information.

Speed of Pulling.—Since the failure of soldered joints often partakes of the nature of creep, the speed of pulling can be expected to influence the strength of soldered joints. Figure 5 shows that within the limits of the tests the shear strength of joints in steel made with 50–50 solder varied linearly with the logarithm of the nominal pulling speed. The strength was almost doubled by changing the testing speed from about 0.001 to 0.1 in. per min. Because the speed of the grips was different from the rate of shearing in the joint, it was not entirely satisfactory for specifying the rate of testing.

Rate of Loading.—With standard equipment, the strength of soldered joints can easily be determined as a function of the rate of loading. Figures 6 and 7 give such results for scarf joints in steel soldered with 50–50 and E solders respectively. As shown in the figures, the shear strength increased by a factor of about two as the rate of frcrease of shearing stress was changed inom about 75 psi. per min. to 35,000 psi. per min.

Time Held at Maximum Load.—To show the importance of this variable in short-time tests, a series of stress rupture tests was made in which the time at maximum load ranged from 0 to 150 min. The results of tests of scarf joints in steel joined with 50–50 solder are given in Fig. 8, and similar data for solder E are given in Fig. 9. The figures show how the shear strength decreases as the time under maximum load is increased. For example, Fig. 8 shows that if the joint must sustain a load for 15 min. at room temperature, that load can be only one half as great as the load required to break the joint in the usual tension test in which the crosshead is moved at 0.06 in. per min.

Another noteworthy observation is that the order of shear strength of two solders may be reversed as the time of sustaining the load is increased. For example, on steel 50–50 solder was about 6 per cent stronger than solder E in the regular tension test at room temperature, but when the maximum load was maintained for 40 min. the joints made with solder E were about 30 per cent stronger than those made with 50–50 solder. Maupin and Swanger (5) have already shown that the long-time creep strength of a joint made with low-tin solders is usually higher than that of a similar joint made with 50–50 solder.

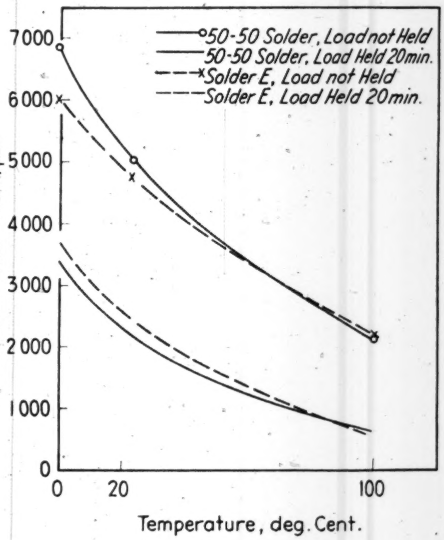


FIG. 10.—Effect of Temperature on the Short-Time Strength of Soldered Joints.

The crosshead was moved 0.06 in. per min. until the maximum load was reached. Steel specimens.

Temperature.—The effects of temperature on the short-time strength of joints

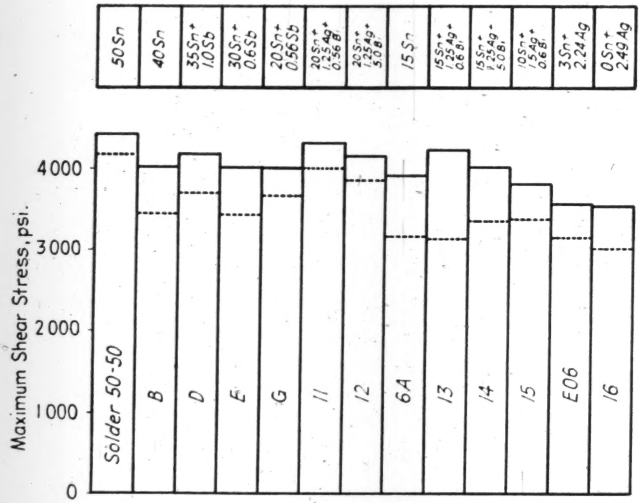


FIG. 11.—Shear Strengths of Scarf Joints in Copper.

Copper strips 0.091 in. thick, angle of scarf = 14½ deg. Dotted and solid lines represent the strengths obtained with first and second solderings, respectively. Speed of crosshead = 0.06 in. per min. Room temperature. Only those elements present in excess of 0.5 per cent are listed.

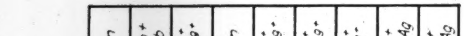


FIG. 12.—Shear Strengths of Scarf Joints in Steel.

Steel strips 0.125 in. thick, angle of scarf = 14½ deg. Dotted and solid lines represent the strengths obtained with first and second solderings, respectively. Speed of crosshead = 0.06 in. per min. Room temperature. Only those elements present in excess of 0.5 per cent are listed.

made with solders E and 50–50 are shown in Fig. 10. These curves were derived from Figs. 8 and 9. In the usual short-time test (pulling speed = 0.06 in. per min.) the shear strength decreased from about 6500 to 2200 psi. as the testing temperature was changed from 0 to 100 C. For rupture accomplished in 20 min., the shear strength decreased from 3500 to 700 psi. as the testing temperature was changed from 0 to 100 C. In the usual tension test the change in shear strength was about 1 per cent per deg. Cent. change in the temperature of testing, whereas in stress-rupture tests lasting 20 min. the change in shear strength per degree Centigrade change in testing temperature was about 1.5 per cent per degree.

Effect of Pretinning.—The effect of pretinning with various solders was studied by testing joints in brass, copper, and steel after first and second solderings. The results are shown in Figs. 3, 4, 11, and 12. Strengths obtained on first soldering are indicated by dotted lines and on second soldering by solid lines. By second soldering is meant the resoldering of the specimens without the removal of the old solder remaining after the first test. All of these tests were conducted at room temperature with a crosshead speed of 0.06 in. per min. Each value shown is the average for four specimens. It is obvious that the joints in copper gave consistently higher strength on second soldering. This difference could not be attributed to pretinning, however, because subsequent tests of copper to copper joints pretinned without being strained were found to be no stronger then those soldered together without pretinning. The reason for the consistently higher strength of the copper joints after second soldering was that work hardening during the first test raised the yield point of the copper in spite of some annealing of the copper during the second soldering operation.

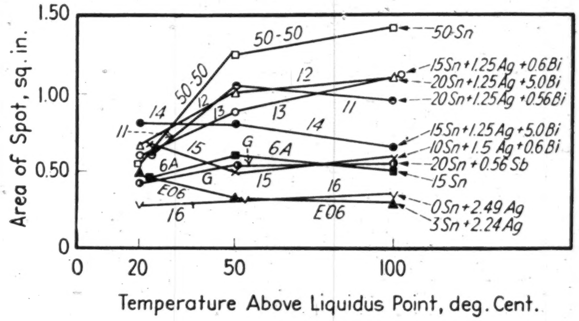


FIG. 13.—The Effect of Temperature on the Spreading of 10 Solders on Copper.

Flux: eutectic $NH_4Cl + ZnCl_2$. Each point is the average of four determinations. Size of solder sample = 0.05 cu. cm. Results for solders G and 50-50, taken from previous work (1). Only those elements present in excess of 0.5 per cent are listed.

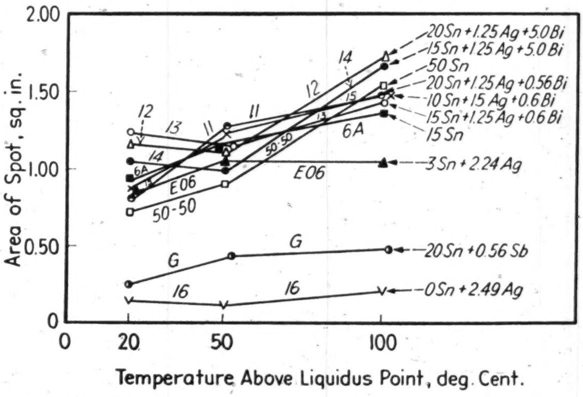


FIG. 14.—The Effect of Temperature on the Spreading of 10 Solders on Black Iron.

Flux: eutectic $NH_4Cl + ZnCl_2$. Each point is the average of four determinations. Size of solder sample = 0.05 cu. cm. Results for solders No. 11 and 50-50 taken from previous work (1). Only those elements present in excess of 0.5 per cent are listed.

In the case of brass and steel, however,

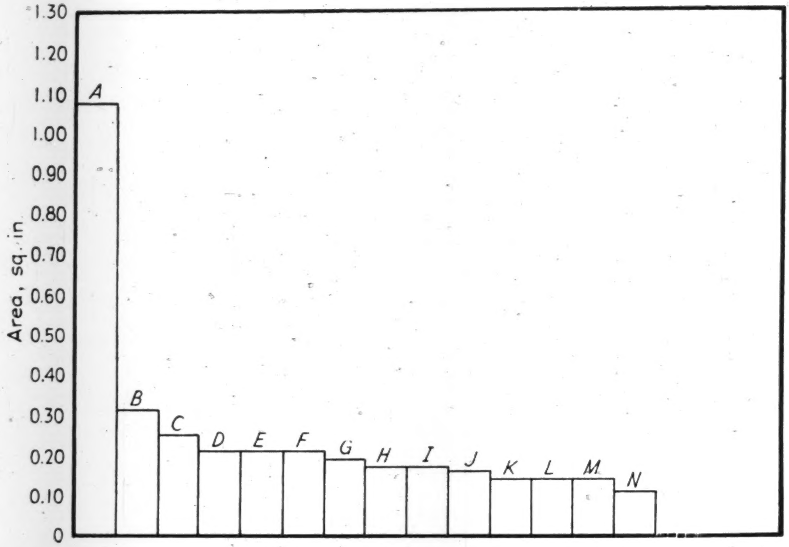


FIG. 15.—The Effect of Different Fluxes on the Spreading of Solder No. 16 on Copper.
Each point is the average of four determinations made at 353 C. (50 C. above the liquidus point). Solder sample = 0.05 cu. cm.

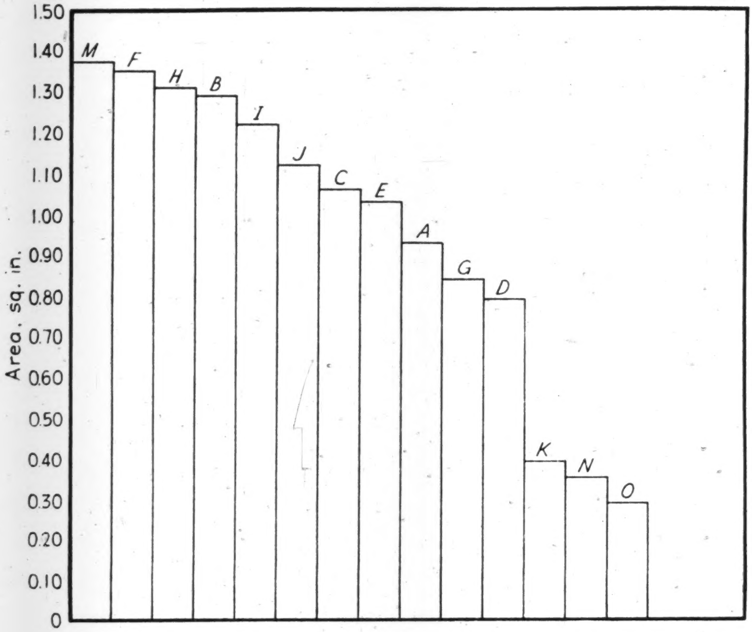


FIG. 16.—The Effect of Different Fluxes on the Spreading of Solder 50–50 on Copper.
Each point is the average of four determinations made at 267 C. (50 C. above the liquidus point). Solder sample = 0.05 cu. cm.

(Figs. 3, 4 and 12), the strength obtained on second soldering was not significantly different from that obtained on first soldering. This would indicate that there is no appreciable advantage in pretinning brass, copper, or steel provided that sound joints can be obtained without it.

Spreading Tests:

In a previous paper the effects of solder composition and temperature on the spreading of six solders were discussed (1). The study has been extended here, with the same procedure, partly to show the relative spreading of solders 11, 12, 13, 14, 15, 16, G, E06, 6A, and 50–50, and partly to show the effect of flux composition on the spreading of solders. Eleven proprietary fluxes and four others, all listed in Table III, were included. The effects of temperature on the spreading of 10 of the solders on copper and black iron are shown in

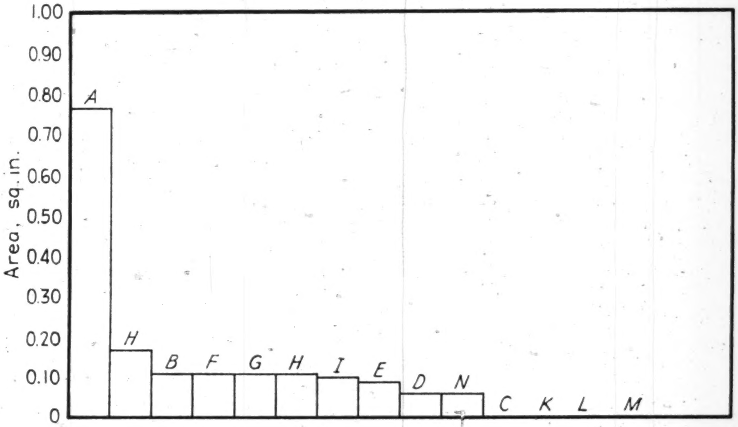


FIG. 17.—The Effect of Different Fluxes on the Spreading of Solder No. 16 on Black Iron.
Each point is the average of four determinations made at 353 C. (50 C. above the liqudus point). Solder sample = 0.05 cu. cm.

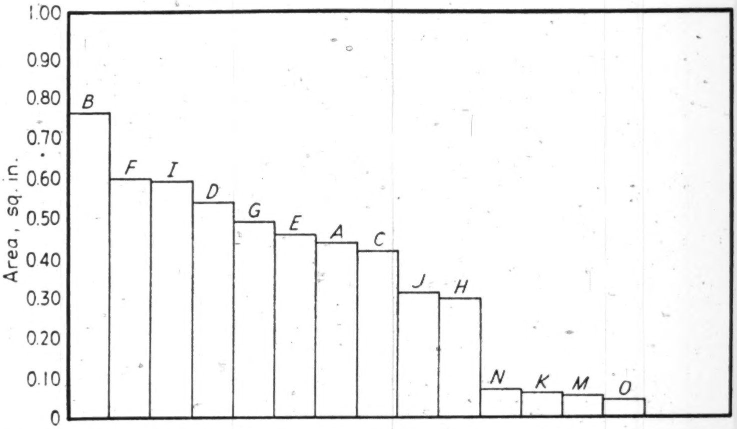


FIG. 18.—The Effect of Different Fluxes on the Spreading of Solder 50–50 on Black Iron.
Each point is the average of four determinations made at 267 C. (50 C. above the liquidus point). Solder sample = 0.05 cu. cm.

Figs. 13 and 14, respectively. A eutectic mixture of zinc and ammonium chlorides was used as the flux. It is evident that for all of the solders except 16 the spreading was greater on iron than on copper. In general, on copper the higher the tin content of the solder the greater was the amount of spreading. On black iron, however, the tin content above 10 per cent seemed to make little, if any, difference in the spreading of solders.

It is evident from Figs. 13 and 14 that small additions of silver and bismuth together promoted greater spreading than that obtained with plain tin-lead solders of the same tin content. High soldering temperatures produced no greater spread of most of the solders on copper than did temperatures only 20 C. above the liquidus. In the case of the tests on iron, however, there was usually a somewhat greater spread at 100 C. above the liquidus than at 20 C. above the liquidus.

The spreading of solder 16 is of unusual interest because the discovery of satisfactory procedures for its use would effect the maximum saving of tin. Accordingly, fourteen fluxes were used with this solder in making spreading tests on copper and on iron. The same number of fluxes were also used with 50–50 solder to furnish a comparison. The results are shown in Figs. 15, 16, 17, and 18.

Flux A was three to four times as effective in promoting the spreading of solder 16 as any other flux investigated. Approximately the same amount of spreading was obtained with solder 16 and flux A on both copper and iron as was obtained with 50–50 solder and the eutectic zinc and ammonium chloride flux when each solder was heated to a temperature 50 C. above its liquidus temperature. In the light of this result one might expect that sounder and stronger joints would be produced with this flux than with other fluxes. In actual tests, however, no appreciable difference in shear strength was found when fluxes A and eutectic zinc-ammonium chlorides were used with solder 16 on steel. For 50–50 solder, a eutectic mixture of zinc and ammonium chlorides promoted the greatest spreading on iron. On copper, however, three proprietary fluxes, M, F, and H promoted slightly greater spreading of 50–50 solder than did the eutectic zinc and ammonium chlorides.

Solder Composition:

The results of tests of joints with the different solders arranged in order of decreasing tin content are given in Figs. 2, 3, 10, and 11. All of the tests were conducted at room temperature and with a crosshead speed of 0.06 in. per min. It is evident that there was little difference between the shear strengths of those solders containing 15 per cent or more tin. Small additional amounts of bismuth, antimony, copper, and silver apparently had little effect upon the strengths of the solders. Although the joints made with solders containing 10 per cent tin, or less, appeared to be relatively weak, it should be kept in mind that results of these tests made under one arbitrarily chosen set of conditions cannot be used to predict solder behavior under other sets of test conditions. Maupin and Swanger (5) have shown that a lead-silver solder was almost four times as strong as 50–50 solder in a creep test at room temperature, although in a short-time test the lead-silver solder was only about three fifths as strong as the 50–50 solder.

According to Figs. 3, 4, and 12 there was practically no difference between the strength of joints in steel and in brass. For copper (Fig. 11), however, the shear strength of the joints was somewhat lower than for brass or steel. The reason for this is that in the case of the brass and steel, the maximum load on the specimen was considerably less than that required to produce yielding (0.2 per cent offset) in the strips, whereas in the case of the copper, the maximum load was approximately twice the load required to produce yielding (0.2 per cent offset) in the strips. It was previously shown (1) that yielding in the members of the joint could be responsible for low values for the shear strength of soldered joints. The strengths of the various solders were in approximately the same order regardless of the materials on which they were used, but the differences in strengths of different solders were less on copper than on brass or steel. This effect, which confirms previous work (1), is also thought to be due to the yielding of the copper.

SUMMARY

1. Investigation was made of 13 solders, 6 of which conformed in composition with the requirements of current A.S.T.M. specifications, 9 with S.A.E. specifications, 6 with Federal specifications, and a commercial 50–50 lead-tin solder. The melting range and density of each solder determined.

2. Tests with different types of soldered joints in copper, brass, and steel led to the conclusion that in determining the relative shear strengths of solders, there were certain marked advantages in using the scarf type of joint. These are:

(*a*) the specimens are inexpensive and can be machined and soldered easily,
(*b*) there is no bending in the specimen during testing,
(*c*) there are no sharp changes of section,
(*d*) the shearing area of the joint is definite and easily measured,
(*e*) fillets are practically nonexistent, and
(*f*) the thickness of the solder film can be easily controlled by inserting short pieces of fine wire for spacers. This eliminates the necessity for machining to close tolerances as required in plug and sleeve joints.

The results obtained with scarf joints were consistent with those obtained with plug and sleeve joints and with butt joints in thin-walled tubes tested in torsion.

3. The component of normal tensile stress in the scarf type of joint can be made so small that its effect on the shear strength is negligible. A scarf angle of about $14\frac{1}{2}$ deg. was found to be satisfactory for brass and steel. Slightly lower values of shear strength were obtained in copper with this type of joint than with plug and sleeve joints and with butt joints in thin wall tubes, but the differences can be attributed to factors other than the form of the joint.

4. In tests to determine the effect of rate of loading, speed of the moving crosshead, time held at maximum load, and temperature on the shear strength of joints soldered with 70–30 lead-tin and 50–50 lead-tin solders, it was found that:

(*a*) the maximum shear stress obtained doubled as the rate of loading was increased from about 75 psi. per min. to 35,000 psi. per min.,
(*b*) the maximum shear stress obtained was doubled as the speed of the crosshead was increased from about 0.001 in. per min. to 0.1 in. per min.,
(*c*) the maximum shear stress more than doubled as the time of holding was decreased from 40 min. to practically zero, and
(*d*) in the usual tension test, the shear strength changed about 1 per cent per deg. Cent.

5. There was very little difference in the shear strength of joints made with solders containing 15 per cent or more tin. The fact that in short-time tests the shear strength of joints made with solders containing 10 per cent or less tin was somewhat less than that of solders of higher tin content should not be construed as meaning that the same would be true in long-time or creep tests. Available data indicate that the reverse would be true. Small amounts of added elements such as bismuth, cadmium, copper, and silver apparently have little effect upon the shear strength of joints at room temperature.

6. In general, with the eutectic mixture of zinc and ammonium chlorides as a flux, the higher the tin content of the solder, the greater was the amount of spreading on copper. With the same flux, the spreading on black iron was practically independent of the tin content for solders containing 10 per cent or more tin. However, with one proprietary flux and lead-silver solder approximately the same amount of spreading was obtained as was obtained with 50–50 lead-tin solder and the eutectic mixture of zinc and ammonium chlorides as a flux. The results of spreading tests indicated that there was little, if any, advantage to be gained by using soldering temperatures higher than 20 C. above the liquidus temperatures for the low-tin solders.

Small additions of silver and bismuth together promoted appreciably greater spreading than that obtained with tin-lead solders of the same tin content.

Acknowledgments:

The authors are indebted to various members of the Engineering Mechanics Section of the National Bureau of Standards for valuable suggestions, to the Pyrometry Section for determining the freezing ranges of the solders, and to the Chemistry Division for analyzing the fluxes. The authors also gratefully acknowledge their indebtedness to Miss Lura Fowkes whose skill in soldering and testing most of the joints and in carrying out the spreading tests greatly expedited the investigation and contributed largely to the reliability of the experimental results.

REFERENCES

(1) J. A. Kies and Wm. F. Roeser, "The Testing and Properties of Low-Tin Solders Listed in Recent Federal Specifications," *Proceedings*, Am. Soc. Testing Mats., Vol. 43, pp. 600–614 (1943).

(2) J. R. Freeman and G. W. Quick, "Tensile Properties of Soldered Joints Under Prolonged Stress," *Metal Industry*, Vol. 24, pp. 7–10 (1926).

(3) R. L. Dowdell, M. E. Fine, F. J. Elliott, and I. C. Mattson, "A New Soft Solder, Lead-Arsenic-Antimony," *Metal Progress*, Vol. 43, No. 1, January, 1943, pp. 56–59, 96.

(4) S. J. Nightingale and O. F. Hudson, "Tin Solders," British Non-Ferrous Metals Research Assn., 2nd edition, London (1942).

(5) A. R. Maupin and W. H. Swanger, "Strength of Sleeve Joints in Copper Tubing Made with Various Lead-Base Solders," Report BMS83, May 5, 1942, U. S. Superintendent of Documents, Washington, D. C.

(6) A. R. Maupin and W. H. Swanger, "Strength of Soft-Soldered Joints in Copper Tubing," Report BMS58, September 20, 1940, U. S. Superintendent of Documents, Washington, D. C.

(7) T. B. Crow, "Some Properties of Soft Soldered Joints," *Journal*, Society of the Chemical Industry, Vol. 43, pp. 65T–70T (1924).

(8) F. N. Rhines and W. A. Anderson, "Substitute Solders," *Metals and Alloys*, Vol. 14, No. 5, November, 1941, pp. 704–711.

(9) R. Chadwick, "The Influence of Surface Alloying on the Strength of Soft Soldered Joints," *Journal*, Institute of Metals, London, Vol. 62, pp. 277–305 (1935).

(10) A. W. Hothersall, D. W. Hopkins, and G. L. Evans, "Factors Affecting the Strength of Soldered Joints Made from Electrotinned Steel Sheet," The Iron and Steel Institute, Advance Copy, February, 1944.

DISCUSSION

Mr. Arthur R. Maupin.[1]—Results of short-time tests on solders and soldered joints can be very misleading because almost any result may be obtained. This paper itself points out the fact that by varying the rate of extension of the specimen the indicated maximum shear stress may be more than doubled. Many other factors, such as the type of joint used, etc., are of importance.

Soldered joints in general, when in service, are subjected to sustained loads, often at elevated temperatures, such as in hot water and steam lines, tanks, cans, rotating parts of machines, etc. The tin-lead solders in general are plastic at all practical temperatures and the rate of creep may be very high at elevated temperatures or for heavy loads.

The maximum safe stresses that should be used for rating solders and for designing soldered joints subjected to these conditions are those obtained by long-time tests for loads at various temperatures, known as creep tests.

The National Bureau of Standards' Reports BMS 58 and 83 show how long-time tests were conducted using sleeve- and rod-type joints.

These tests showed that the strength of a joint by short-time tests at room temperature, made with 50–50 solder, was eighteen to twenty-four times the strength of an identical joint subjected to long-time tests. Comparison of the long-time and short-time tests for many other solders showed that the maximum permissible shear stresses from the short-time tests were many times those from the long-time and, furthermore, no relationship between the two was found. This conclusion also is indicated in this paper in the tests on "effects of time and temperature."

Conservation restrictions on tin in solders have caused lower tin solders, such as 5 per cent to 35 per cent tin solders and lead-silver solders, to be used where higher tin solders once were used. Many industries and solder users object to the high-lead solders (and some refuse to use them) because of indicated low strength. Short-time tests show that these solders are weaker than high tin. Former long-time tests showed the reverse results—that high lead solders are stronger than high tin, and this also is indicated by tests in this paper.

This is a very interesting and well prepared paper on short-time tests. Short-time tests have some significance, but in most cases they may be misleading for they tell very little about soldered joints and how they may actually behave in practice. Unless short-time tests can be used to predict long-time conditions, they may lead to dangerous conclusions.

The tests that show flux number "A" (45 per cent $ZnCl_2$, 5.3 per cent NH_4Cl, 3.7 per cent $SnCl_2$ in water vehicle) to be very satisfactory for the silver-lead solder are highly welcomed. The main problem with this high-melting solder has been selection of a suitable flux.

Mr. W. F. Roeser[2] (*author's closure, by letter*).—The limitations of short-time tests of soldered joints were recognized and pointed out in the paper.

---

[1] Consultant, Tin-Lead, Solders and Babbitts Conservation Div., War Production Board, Washington, D. C.

[2] Principal Metallurgist, National Bureau of Standards, Washington, D. C.

There has been and still is a general feeling among many users of solders that satisfactory joints cannot be made with low-tin solders. As a matter of fact Mr. Maupin states in his discussion, —"Many industries and solder users object to the high-lead solders (and some refuse to use them) because of indicated low strength. Short-time tests show that these solders are weaker than high tin."

One of the useful purposes of short-time tests of soldered joints, that Mr. Maupin has not acknowledged, is that they may be used to show that satisfactory joints can be made with low-tin solders. Some data have been published which indicate that joints made with low-tin solders were not as strong as those made with the higher tin solders. However, the results obtained in this investigation show that there is very little difference in the shear strength of joints made with solders containing 15 per cent or more tin. As these results were obtained in short-time tests, and as other investigations have shown that the low-tin solders were stronger than the higher tin solders in long-time tests, we fail to see any justification for any claim that the lower tin solders are weaker than the higher tin solders in any respect.

SYMPOSIUM ON ANALYTICAL COLORIMETRY AND PHOTOMETRY

Opening Remarks By G. E. F. Lundell,[1] Chairman of Symposium Committee

All who have followed applied chemical analysis appreciate the strain that modern industrial requirements placed on chemical analysis following the turn of the century. The enormous number of determinations demanded, and the time allowed for them, threatened completely to swamp chemical analysis.

From the analyst's search for simpler and more rapid methods have come physical methods, such as emission spectrographic, and chemico-physical methods, such as potentiometric, colorimetric, and photometric, that require little or no chemical treatment.

The rapid improvement, within recent years, of apparatus for measuring the absorption of light by aqueous solutions, and the development of superior methods of test based on the use of such apparatus, have led to a constantly increasing use of photometric methods in analytical chemistry.

Committee E-3 on Chemical Analysis of Metals considered that it would be helpful if a symposium were held on this important development in chemical analysis. The papers to follow cover principles, apparatus, and applications. These include topics such as light, the deviation and use of laws, chemical principles, photoelectric cells, glass filters, filter photometers, spectrophotometers, the use of photometric methods in testing certain ferrous and nonferrous metals, and a selected bibliography.

---

[1] Chairman of Committee E-3 on Chemical Analysis of Metals, and, Chief, Chemistry Div., National Bureau of Standards, Washington, D. C.

INTRODUCTION—TRENDS IN ANALYTICAL CHEMISTRY

By B. L. Clarke[1]

Committee E-3 is unique in the A.S.T.M. in that we are all primarily chemists. We have this in common with the Division of Analytical and Microchemistry in the American Chemical Society, that we are concerned with increasing the knowledge of the chemical principles underlying analysis. But as we function in the A.S.T.M., the emphasis is on application. The straightforward objective of Committee E-3 is to devise techniques and apparatus that will permit the most efficient analysis of metallic systems for the components and with the accuracies designated in A.S.T.M. specifications. Thus our objective is narrower than that of our prototype in the Chemical Society. But it is clear that we of this Committee would be disastrously handicapped in the practical application of chemical principles to our problems if we did not possess the theoretical and academic background that is connoted by the American Chemical Society, and if we were deprived of the current and continuing association with those colleagues of ours in that society whose activities belong within the sphere of pure science.

This Symposium on Analytical Colorimetry and Photometry is illustrative of current trends in analytical chemistry. In other words, the trend in analytical chemistry is definitely toward instrumental methods. In the last century, when analytical chemistry was a neglected stepchild of the science, the chief handicap of analysts was the lack of special apparatus and equipment consciously designed for the peculiar requirements of their work.

That handicap is now being overcome so rapidly that I sometimes wonder whether the whole character of the profession of chemical analysis is not undergoing revolutionary changes that are not fully recognized as such. In what some of us might be inclined to call the "good old days," an analytical chemist was considered to be well trained if he knew his fundamental chemistry and was able to adapt the beakers, test tubes, and crucibles of his synthesist colleagues to his special problems of manipulation.

But nowadays, with our polarographs, spectrographs, spectrophotometers, electron microscopes, mass spectrometers, etc., the analyst will be quite lost if his training and experience have stopped there. He must, in addition, possess some of the skills of the physicist, the astronomer, and the mechanical, electrical, electronics, electro-optical, and possibly stationary engineer. And it is quite essential that he be a good salesman, since these modern analytical instruments are expensive and research directors have to be convinced.

Quite seriously, it is apparent to us, and I hope it soon becomes so to the colleges, that a curriculum adequate a few years ago for training analysts is now grossly inadequate. It is greatly to our interests to see that these curricula are modernized. For one thing, physicists are being seen more and more manning instruments in analytical laboratories because available chemists have not the right kind of training. If we do not want to see the physicists preempt a field which should remain our own, we must see to it that chemists receive the right kind of training.

---

[1] Chairman of the New York Section of the Am. Chemical Soc., and, Bell Telephone Laboratories, Inc., New York, N. Y.

The trend in analytical chemistry is obviously towards instrumental methods. Not so obvious, perhaps, is that the trend in the training of analytical chemists is not sufficiently parallel. I submit that it is of great importance to establish such a parallelism.

COLORIMETRIC ANALYSIS AND BEER'S LAW

BY JOHN L. HAGUE[1]

Analytical colorimetry is not a new subject. The "laws" to be discussed in this paper have all been formulated before. Rather, they are the type of thing that one is inclined to take for granted. A short review may, therefore, be an aid in considering the other papers of this symposium, as well as avoiding some repetition in the treatment of Beer's law.

As an illustration, the laws governing the absorption of radiant energy by solutions were demonstrated 75 yr. and more ago. Texts describing the use of colorimetric methods as applied to analytical chemistry date from 1873 (12). Perhaps the recent interest in analytical colorimetry can best be attributed to the development in the last decade of more or less reliable photoelectric devices which enable one to evaluate the energies involved in a reasonably reproducible and objective fashion. The intent is to present the principles of Bouguer's and Beer's laws in a form suitable to explaining their application to such instruments.

As most of our laws are formulated from data taken in the laboratory, we should first state something concerning the general conditions under which the measurements are made. If a beam of radiant energy of intensity I_o is directed toward a homogeneous substance, a part (I_R) of the energy will be reflected or otherwise lost, a part (I_A) will be absorbed by the medium, and a part (I_T) will be transmitted. In general, then, we may say that:

$$I_o = I_R + I_A + I_T \ldots\ldots (1)$$

In analytical colorimetry one usually finds it necessary, as in gravimetric or volumetric analyses, to run a blank determination to correct for reflection losses, impurities in the reagents, etc. In general, the practice of taking the initial reading through this blank solution has come into common use. Under these conditions, we generally assume that reflection losses are canceled, and Eq. 1 can be modified as follows:

$$I_o = I_A + I_T \ldots\ldots\ldots (2)$$

If a monochromatic beam of radiant energy is directed through a homogeneous body, it has been demonstrated that, if correction is assumed for reflected light, the ratio of the energies of the transmitted and incident beams will be constant and independent of the absolute value of I_o. For a unit thickness, arbitrarily 1 cm., of the absorbing medium, we may use the following expression:

$$\frac{I_T}{I_o} = t \ldots\ldots\ldots\ldots (3)$$

where t = transmissivity of absorbing medium.

In Eq. 3, we have arbitrarily limited ourselves to a unit thickness of the absorbing medium so that it becomes a matter of interest to determine to what degree the transmitted energy varies with the thickness of the absorbing medium. To illustrate the point, Fig. 1 proposes a series of unit absorbing mediums so constituted that each of itself will transmit (and absorb) one half of the incident (I_o, assuming no reflection losses) radiant energy striking it. Each unit in the series will then transmit one half of the radiant energy incident upon it, and the radiant energy transmitted by the series will decrease in a geometrical progression expressed by the following equation:

---

[1] Chemist, National Bureau of Standards, Washington, D. C.

$$I_T = I_o \left(\tfrac{1}{2}\right)^n$$

where n = number of unit absorbing mediums.

In the more general case illustrated in Fig. 2, we shall assume that, for some homogeneous body with the transmitting capacity, or transmissivity, t, the portion of the incident energy transmitted at any point l distant in the absorbing medium can be expressed by the general equation:

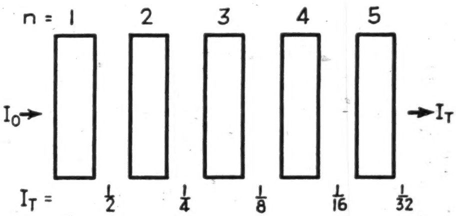


FIG. 1.—A Specific Example of the Transmission of Radiant Energy.

$$I_T = I_o t^l$$

which may be simplified into the form:

$$\log_{10} \frac{I_T}{I_o} = l \log_{10} t = -\kappa l \ldots (4)$$

where kappa, κ, the extinction coefficient, is equal to $-\log_{10} t$. In practice, the ratio $\frac{I_T}{I_O}$ is sometimes called transmittancy, T, and $\frac{I_T}{I_O} \times 100 = \%T$ = percentage transmittancy. In this case I_T refers to that part of a beam of radiant energy transmitted by the test solution, and I_o refers to that part transmitted by the blank or solvent. The quantity $-\log_{10} \frac{I_T}{I_O}$, is sometimes called density, D, or extinction, E. In general,

$$\kappa l = D = E = -\log_{10} \frac{I_T}{I_o}$$

$$= \log_{10} \frac{1}{\text{transmittancy}} \ldots (5)$$

Our primary interest is, of course, in knowing how the absorption of light varies with the concentration of a solution. Beer (**1**)[2] has shown that it is a matter of indifference with many solutions whether the concentration or thickness is varied, because the absorption is dependent on the number of absorbing molecules. In short, it may be shown that in such cases the relation between transmittancy and concentration is of the same form as that for transmittancy and thickness, and hence:

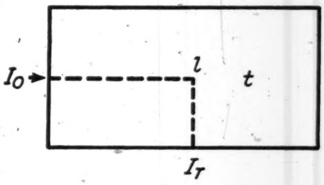


FIG. 2.—A General Example of the Transmission of Radiant Energy.

$$\log_{10} \frac{I_T}{I_o} = -\epsilon l c \ldots\ldots\ldots (6)$$

The numerical value of epsilon, ϵ, will depend upon the method of expressing the concentration; if we express the concentration in moles per liter (molar), then at 1 cm. cell thickness, ϵ may be called the molar, or molecular, extinction coefficient.

---

[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 717.

In the development of the formulas already given, we have imposed two experimental conditions: (*1*) the incident energy shall be monochromatic in character, and (*2*) the incident energy shall be measured through a "blank." As regards the first condition, with the possible exception of a few instruments designed to use mercury-vapor-lamp line spectra, we do not realize a strictly monochromatic source, although some spectrophotometers do isolate band spectra of 1 to 10 mμ width. In general, filter photometers of the photoelectric type and some of the spectrophotometers designed for analytical work isolate much wider bands, and depend on a stable combination of illuminant, filter or monochromator, and spectral sensitivity and illumination-current relationship of the measuring cell to give reproducible results. If any of these conditions change sufficiently, the usefulness of the instrument's calibration curve or constant is lost, and the instrument must be recalibrated for the particular determinations concerned. In addition, as the width of the isolated spectral band increases, such instruments suffer from the fact that the spectral selectivity of the solution being measured may seriously alter the spectral characteristics of the radiant energy reaching the photocell, particularly for measurements made at a wave length where the transmittancy of the absorbing solution changes rapidly with change in wave length. As a result, such solutions may sometimes appear not to obey Beer's law, although with sufficiently monochromatic light the solutions may, in fact, obey Beer's law (**5**).

Concerning the second condition, one can obtain satisfactory results by setting the 100 per cent transmittancy point through the blank (for the type of calculation employed, see the paper by Müller (**6**)), but such a system of measurement requires that a blank be available at the time a measurement is to be made. Furthermore, even when measurements are made against a blank, particularly in the analysis of iron and steel and certain of the non-ferrous alloys if separations are not made, the calibration curve does not pass through the origin, owing to the absorption of a constant amount of radiant energy by the major element or for other reasons. For example, curves of the type illustrated by the solid lines in Figs. 3 and 4 are obtained, and such

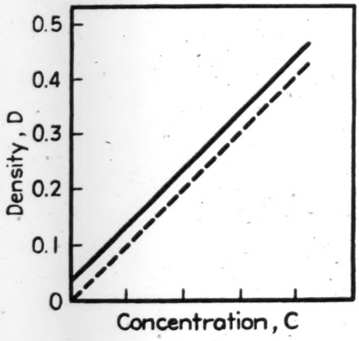


FIG. 3.—Density-Concentration Analytical Curves Illustrating Conformance to Beer's Law.

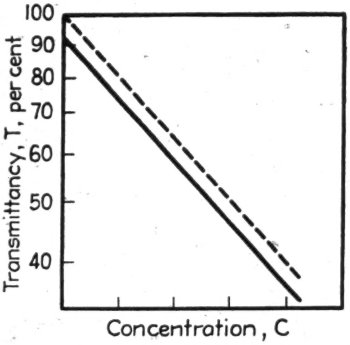


FIG. 4.—Transmittancy-Concentration Analytical Curves Illustrating Conformance to Beer's Law.

curves can be described by a modification of Beer's law (**3**):

$$\log_{10}T_2 - \log_{10}T_1 = -\epsilon l(C_2 - C_1) \quad (7)$$

or

$$D_2 - D_1 = \epsilon l(C_2 - C_1)$$

The slope of the line (the instrument constant for a determination) for a particular cell length can be determined by measuring the transmittancy (or density) of two solutions, one with as low a concentration of the element being determined as is practical, and the other near the upper limit of the usable portion of the line. These curves may be recalculated to a zero concentration, 100 per cent transmittancy (or preferably to a zero concentration, zero density) origin, because the concentration is then directly proportional to density if one can correct for this "background blank." Values can be easily obtained by multiplying the observed density values by some constant suitable to the determination at hand. In general, we have preferred to make our determinations by setting the zero density or 100 per cent transmittancy point against water or some other suitable reference liquid, and to determine the concentration by use of such a constant or "factor." Values obtained in this way are then corrected for a blank (both chemical and background) determined on a sample of like type containing none, or a low known concentration, of the element being determined. The advantage of such a system is that the blank need be determined only occasionally or if a new lot of reagents is used. Such a system is, however, restricted to solutions giving a reproducible "background," and the use of a "factor" is further restricted to solutions that obey Beer's law.

For example, data of the type given by J. L. Hague and H. A. Bright, in the *Journal of Research,* Nat. Bureau Standards, Vol. 26, No. 5, p. 409 (1941), for determinations of phosphorus are used in the following manner:

A transmittancy value ($\%T_1$) of 94.5 per cent was observed for National Bureau of Standards standard sample of ingot iron 55*a*, which contains 0.004 per cent (C_1) of phosphorus. A transmittancy value ($\%T_2$) of 45.0 per cent was observed for National Bureau of Standards standard sample of steel 8*e*, which contains 0.099 per cent (C_2) of phosphorus. Substituting in the equation, $\log_{10} \%T_2 - \log_{10} \%T_1 = -k(C_2 - C_1)$

$$\log \%T_1 = 1.9754, \qquad C_1 = 0.004$$
$$\log \%T_2 = 1.6532, \qquad C_2 = 0.099$$

$$-k = \frac{\log \%T_2 - \log \%T_1}{C_2 - C_1}$$

$$= \frac{1.6532 - 1.9754}{0.099 - 0.004} = -3.39$$

A concentration (percentage of phosphorus, uncorrected for blank) *versus* transmittancy table may be calculated by substitution of observed transmittancy values ($\%T_{obs}$) calculated to a 100 per cent transmittancy origin:

$$C = \frac{\log 100 - \log \%T_{obs}}{3.39}$$

For standard sample 55*a*, considered as a blank determination,

$$C = \frac{2 - 1.9754}{3.39} = 0.007 \text{ per cent}$$

Since the sample used in determining the blank contains 0.004 per cent phosphorus, the actual blank is:

$$0.007 - 0.004 = 0.003 \text{ "per cent phosphorus"}$$

For standard sample 8*e*, considered as an unknown sample:

$$C = \frac{2 - 1.6532}{3.39} = 0.102 \text{ (uncorrected)}$$

The corrected value for phosphorus is then:

$$0.102 - 0.003 = 0.099 \text{ per cent phosphorus}$$

Actually, the calculations are usually much simpler, since most instruments designed for analytical determinations are now equipped with density, extinction, or other logarithmic factor scales; and properly so, as the analyst is concerned primarily with the radiant energy absorbed by the solution. Under such conditions, we may visualize the example as follows:

A density value (D_1) of 0.025 corresponds to National Bureau of Standards standard sample 55*a*, which contains 0.004 per cent (C_1) of phosphorus. A density value (D_2) of 0.347 corresponds to National Bureau of Standards standard sample 8*e*, which contains 0.099 per cent (C_2) of phosphorus. Substitution in the equation $D_2 - D_1 = k\,(C_2 - C_1)$:

$$k = \frac{(0.347 - 0.025)}{(0.099 - 0.004)} = 3.39$$

In practice, the reciprocal of *k* is used as the instrumental "factor:"

$$\frac{1}{k} = \frac{1}{3.39} = 0.295$$

For standard sample 55*a*, which contains 0.004 per cent phosphorus, considered as a blank:

$$0.025 \times 0.295 = 0.007$$
$$0.007 - 0.004 = 0.003 = \text{blank}$$

For standard sample 8*e*, considered as an unknown sample:

$$0.347 \times 0.295 = 0.102 \text{ (uncorrected)}$$
$$0.102 - 0.003 = 0.099 \text{ (phosphorus value corrected for the blank)}$$

A second system, sometimes called the "difference" method (**13**), depends on the additive nature of density values if measured under the same spectral conditions. Such a system is applicable regardless of variation in "background" density if the color due to the elements being determined can be "bleached" by the addition of a suitable reagent without affecting the color of the other elements present (**9**). Or, at times, a suitable solution of the sample may be prepared without developing the color reaction of the element being determined (**2**). Other variations are also possible (**10**), but in any case, the 100 per cent transmittancy (or zero density) point is usually set on this "bleached" or "undeveloped" sample, and the transmittancy of the test solution determined. A separate blank, if necessary, should be run under the same conditions to correct for any impurities in the reagents. If the solutions obey Beer's law, the curves may be recalculated and a factor used as in the previous case. Such a system is, however, usually applicable to solutions which do not appear to obey Beer's law, when results are read from a graph prepared from data obtained from samples containing known amounts of the element being determined and treated in the same way. This method of correcting for a variable background is of general application under proper conditions, and does not require the analyst to know the actual percentages of the interfering elements.

The discussion to this point has, of course, presupposed that the analyst has so developed his chemical procedure that the measured absorption of radiant energy is specific for the element being determined, and that any color produced is not given by any other element present or likely to be encountered in the material being analyzed. Such a requirement as to specificity is also common to other methods of analysis claiming to give accurate values. (A precise value may be seriously in error, if some other element gives a similar reaction, or inhibits the reaction in question, unknown to the analyst.) Many determinations are made, therefore, using specific, reproducible, chemical procedures, by comparing the data obtained with empirical calibration curves prepared under the same conditions and not obeying Beer's law.

Two elements reacting with the same reagent may give, on occasion, solutions whose absorption characteristics are sufficiently different that a wave length can be chosen for measurements on each element independently, and such solutions offer no practical difficulties. (For an example applied to rare earth mixtures, see the paper by Rodden (**8**).)

Usually, however, the absorption characteristics of each overlap the other, and resort must be made to indirect methods. It has been shown that density measurements at two suitable wave lengths will suffice for a two component system, provided that each component obeys Beer's law for the two wave lengths chosen. (For an example of the general case of multicomponent systems, see Twyman and Allsopp (12). For an example of the type of calculation employed in the practical case, see the paper by Knudson, Meloche, and Juday (4).)

Such systems have had general use in other fields of analytical chemistry, particularly organic and biochemistry, but do not appear to have received much attention in metallurgical analysis. A few examples should be noted. H. Pinsl (7) has proposed a method for the determination of titanium and vanadium based on the colors produced with hydrogen peroxide, making density measurements at the 436 and 546 mμ (or 578 mμ) mercury lines with a Pulfrich "step-photometer." A graphic curve system for such mixtures is also given. A method somewhat similar in principle, although employing graphical curves, has been proposed (11) for the determination of manganese and chromium, based on the colors produced by ammonium persulfate in the presence of silver catalyst.

Much could be said regarding the reasons why solutions do not obey Beer's law, as well as certain aspects of the accuracy of the systems of measurement in common use. The fact remains, however, that many thousands of satisfactory determinations a year are being made in the iron and steel industry alone by colorimetric methods, many with little regard to the foregoing, samples and standards being run by the same procedure and compared either visually or photoelectrically. A little regard for the physical and chemical principles of photoelectric absorptiometry should, in many cases, allow optical corrections to substitute for chemical separations with a resultant speeding up of the work, and with little, if any, loss in accuracy.

REFERENCES

(1) Beer, "Bestimmung der Absorption des rothen Lichts in farbigen Flüssigkeiten," *Ann. Physik*, Vol. 86, p. 78 (1852).

(2) W. J. Boyer, Rustless Iron and Steel Corp., Baltimore, Md., private communication.

(3) J. L. Hague and H. A. Bright, "Colorimetric Determination of Phosphorus in Steel and Cast Iron," *Journal of Research*, Nat. Bureau Standards, Vol. 26, No. 5, p. 4[illegible]8 (1941).

(4) H. W. Knudson, V. W. Meloche, and C. Juday, *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 12, pp. 715–717 (1940).

(5) G. Kortüm, *Angewandte Chemie*, Vol. 50, pp. 196–198 (1937).

(6) R. H. Müller, *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 7, p. 361 (1935).

(7) H. Pinsl, *Angewandte Chemie*, Vol. 50, pp. 118–120 (1937).

(8) C. J. Rodden, "Spectrophotometric Determination of Praseodymium, Neodymium and Samarium," *Journal of Research*, Nat. Bureau Standards, Vol. 26, No. 6, p. 567 (1941).

(9) G. P. Rowland, *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 11, p. 444 (1939).

(10) E. B. Sandell, "Colorimetric Determination of Traces of Metals," Interscience Publishers, New York, N. Y., pp. 62–63 (1944).

(11) R. W. Silverthorn and J. A. Curtis, *Metals and Alloys*, Vol. 15, No. 2, p. 245, (1942).

(12) F. Twyman and C. B. Allsopp, "The Practice of Absorption Spectrophotometry with Hilger Instruments," Second Edition, Adam Hilger, Ltd., London, pp. 41–44 (1934).

(13) E. J. Vaughan, Lectures on "The Use of the Spekker Photo-Electric Absorptiometer in Metallurgical Analysis" (1941) and "Further Advances in the Use of the Spekker Photo-Electric Absorptiometer in Metallurgical Analysis" (1942), Institute of Chemistry, London.

FILTER PHOTOMETERS

By A. E. Ruehle[1]

Spectrophotometry has been defined[2] as the measurement of relative radiant energy as a function of wave length. In analytical work, however, a spectrophotometer is usually used to select only a single portion of the spectrum and to measure the intensity of the radiant energy selected in arbitrary units. A filter photometer, by this definition, is an abridged spectrophotometer, which selects the portion of the spectrum to be measured by filtering out all other portions to which the detection device employed is sensitive. (Schematic diagrams of two types of filter photometers are shown in Fig. 1.) In chemical analysis, therefore, a filter photometer may enjoy the same advantages and may be subject to the same limitations as prism or grating spectrophotometers, except that additional limitations are imposed by virtue of the greater spectral band width selected by the filter and the limited number of suitable filters available. To offset these limitations, a simpler and less expensive instrument can be made, which for many purposes is the equal of the more complex instruments. It is the aim of this paper to examine these limitations from the standpoint of preventing misapplication of a very worthwhile tool.

Let us consider what might reasonably be expected from a good spectrophotometer, as applied to photometric analysis, and see how a filter photometer meets our requirements:

1. Narrow portion of the spectrum selected, ideally monochromatic light.
2. Relative freedom from stray (unwanted) light at all wave lengths.
3. High accuracy on the intensity scale.
   A.—Methods of Intensity Variation
      (*a*) Calibrated aperture
      (*b*) Calibrated polarizing prisms
      (*c*) Calibrated wedge
      (*d*) Calibrated length of cell
      (*e*) Calibrated concentration of sample
   B.—Detection Devices
      (*a*) Eye
      (*b*) Photographic plate
      (*c*) Photocell with or without amplifier
         (*1*) Barrier layer cell
         (*2*) Phototubes
4. Objectivity.
5. Speed.
   A.—Ease of reading wave lengths and intensity scales.
   B.—Simplicity (not too many gadgets).
   C.—Wide choice of cell lengths.
   D.—Ease of cleaning cells.
6. Range from 200 to 1000 mμ, with ready selection of desired wave length.
7. Sensitivity—good for low intensities.
8. Ruggedness and compactness—optically, electrically, and mechanically stable enough to stand routine use by unspecialized operators, yet not unduly bulky.
9. Versatility—should be usable for transmission, reflection, and fluorescence.
10. Cost—should be as low as is consistent with first quality workmanship and materials.

In regard to points 3, 4, 5, 7, 8, 9, and 10, filter photometers for certain chemical analyses can be equal to, or superior to, the ordinary prism or grating instruments. Advances in producing filters, as described in Gage's paper in this symposium,[3] promise a partial answer to point 6. The greatest limitations of filter photometers, therefore, appear to be imposed by the imperfect selection of light of high spectral purity inherent in the use of filters.

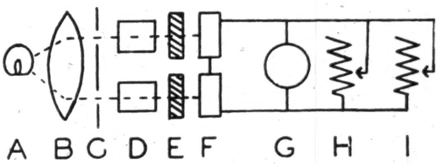
---

[1] Chief Chemist, Austin Magnesium Plant, International Minerals and Chemical Corp., Austin, Tex.

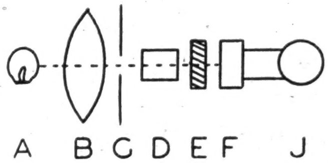
[2] Committee Report, *Journal Optical Soc. Am.*, Vol. 10, p. 169 (1925)

[3] See p. 720.

If the spectral region selected by the filter is exactly at the peak of the absorption band of the substance being measured, maximum sensitivity and accuracy for the analysis will be possible. However, if the absorption band is narrow, or the limitations of range for the instrument make it necessary to make the measurements on the side of the absorption band, sensitivity will be lost and the Lambert-Beer law will appear not to be followed. Light passed by the filter in regions other than at or near the peak of the absorption band is "stray light" in its effect on the analytical curve just as surely as is an internal reflection in the instrument. The analytical curve will generally be nonlinear to an extent dependent upon the amount of stray light reaching the detector.[4] In passing, it is easy to see why the ordinary colorimeter is relatively limited in both sensitivity and accuracy, since it depends upon differences in transmission of the whole visible spectrum with changes in concentration. The percentage change in the whole is much less for a given change in concentration than is the percentage change in the region where the maximum absorption occurs.



Two-Cell Type



Single-Cell Type

FIG. 1. Diagrams of Filter Photometers.

A—Light source.
B—Lens.
C—Slits.
D—Absorption cells.
E—Filters.
F—Photocells.
G—Galvanometer.
H—Zero adjustment.
I—Slide wire resistance.
J—Milliammeter.
Dotted line represents the light path.
Solid line represents the electrical circuit.

Fortunately the absorption bands of the majority of colored compounds of analytical interest are broad, so that excellent results are possible in a very large number of cases. Even where conditions are not perfect, the only ill effect may be a small loss in relative sensitivity and a nonlinear analytical curve, requiring extra points for calibration. It should, however, be pointed out that the chance of interference due to other colored components in the solution is greater, not only because of the broader spectral region selected but because the unwanted light passed by the filter may be absorbed by the interfering compound more in one case than in another.

In applying a filter photometer to a new analysis it is wise to determine the absorption curves of the colored compound and of possible interfering compounds as accurately as possible with the best spectrophotometer available, after which a proper choice of filters will frequently permit application of the filter photometer to rapid routine determination with a high degree of accuracy.

---

[4] M. N. States and J. C. Anderson, "The Significance of Stray Light in Photoelectric Filter Photometers," *Journal Optical Soc. Am.*, Vol. 32, p. 659 (1942).

GLASS PHOTOMETRIC FILTERS

By O. A. Gage[1]

The making of colored glass is an art, and an especially difficult one if hue is to be carefully controlled. The coloring agents are limited to certain metallic oxides which react differently with various glass bases. The hue in all glasses is determined by the amount of the coloring agent present. In some glasses, however, the color is dependent not only on batch but also on the heat treatment given the glass. From a certain batch a glass can be obtained which may be clear, yellow, or red, depending on the way it is handled after forming.

In a discussion of filters, it is necessary to define the term "transmission." Unfortunately, this word has different meanings in current literature. "Transmission" will be considered here as the ratio between the light that leaves the glass to the light that is incident upon it. Thus all losses are taken into account. The most important of these are reflection losses at the two surfaces and absorption in the glass itself. In some discussions, the word "transmission" does not include in the losses those due to reflection. For example, with glass index of refraction of 1.5, the transmission, as defined in this article, cannot exceed 92 per cent, even with no absorption or losses other than reflection. If surface reflection is not considered, the value then becomes 100 per cent for a perfect glass.

The absorption bands of glass are in most cases broad. For colorimetric work, limited regions are needed and a monochromatic light is highly desirable. The most successful way to obtain monochromatic light with a glass filter is by using gaseous light-sources and suitable filters to isolate one of the visible spectral lines. This is most effective but gives a limited number of wave lengths.

The Christiansen filters also give monochromatic light for a number of different wave lengths, but they have certain limitations.

Glass filters may be used with continuous light sources to obtain narrow band filters. The maximum transmission will be low, but modern amplifying equipment overcomes this.

Figure 1(*a*) gives the transmissions of a number of filters that absorb short wave length radiant energy with cutoffs distributed over the visible spectrum. Figure 1(*b*) gives a series of the reverse type, but the cutoffs are not so abrupt. A series of narrow band transmissions can be obtained by combining the figures of these two groups. Results are shown in Figure 1(*c*).

Of interest in colorimetry are the curves for green glasses shown in Fig. 2, those for ambers and yellows without sharp cutoff shown in Fig. 3, and those for a minus green group shown in Fig. 4. The didymium filter, Fig. 5, with its narrow absorption bands of very low transmission is especially useful.

It should be remembered that all of these filters have infrared and may have some ultraviolet transmission. Figure 6 gives the total transmission of a narrow band filter which has a very considerable transmission in the infrared. This energy may be absorbed by the receiver.

---

[1] Manager, Optical Sales Dept., Corning Glass Works, Corning, N. Y.

There is a general idea that glass is not affected by water. Unfortunately, that is not true of all glasses. In a very few cases the surface of the filter may be attacked by atmospheric moisture. When the surface is so etched, it can be reclaimed by repolishing.

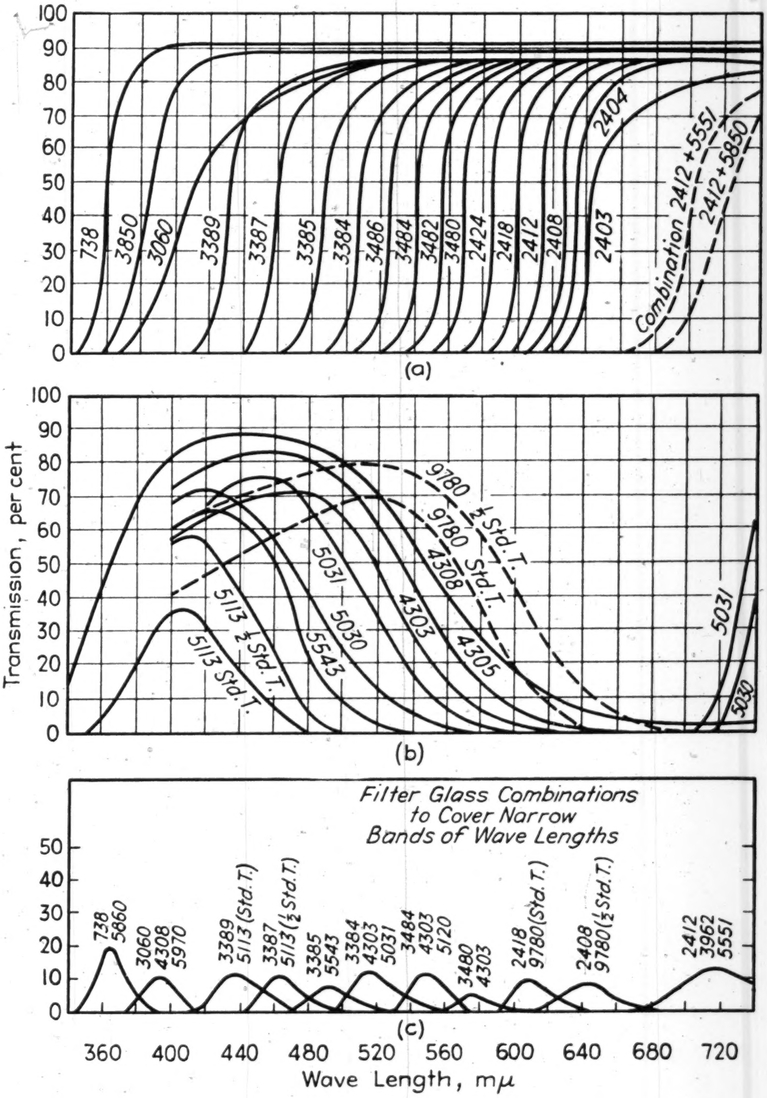


FIG. 1.—Transmission of Filters.

The permanency of the hue of colored glasses is good. Up to date, there is no evidence of a hue change in properly chosen glasses, although colors of this type have been used under exacting conditions in railway, ship, and air service for years. Changes in temperature, however, will produce changes in hue. As the temperature increases, the absorption bands become wider. This effect is especially evident in the reds and ambers of Fig. 1(*a*).

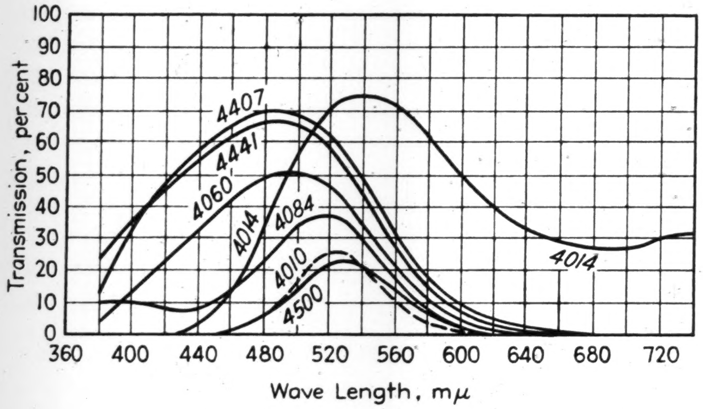


FIG. 2.—Transmission of Green Glasses.

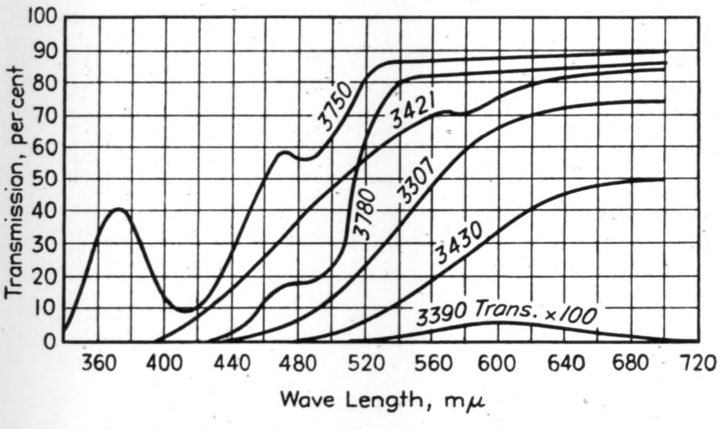


FIG. 3.—Transmission of Amber and Yellow Glasses.

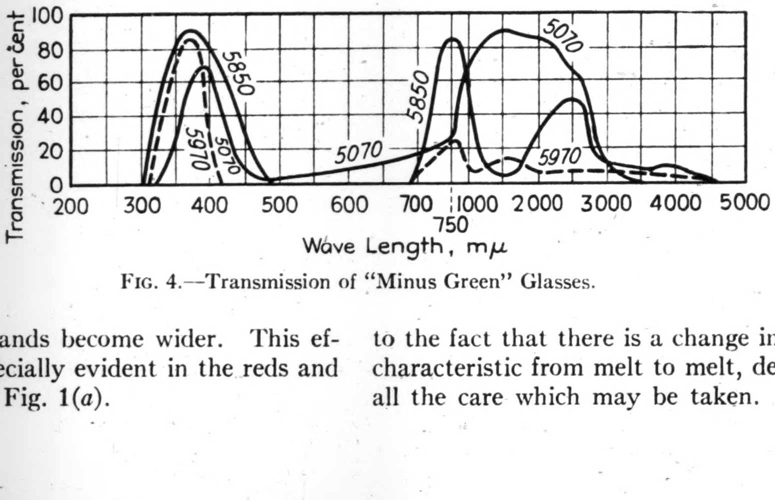


FIG. 4.—Transmission of "Minus Green" Glasses.

As indicated earlier, the most serious problem is the control of chromaticity from shipment to shipment. This is due to the fact that there is a change in this characteristic from melt to melt, despite all the care which may be taken. One way of supplying similar glass is to assign a number to each melt and obtain a spectrophotometric curve for that melt. If the user gives the glass and the melt numbers, then from these data can be computed the thickness for another melt that will be equivalent. This correction is particularly easy in the case of blues, greens, and some yellows, because in these glasses a colored silicate is dissolved in the clear silicates. Figure 7 shows the transmission of a series of melts of a blue glass all ground to the same thickness. Figure 8 shows these data corrected by modifying thickness of the glasses from the different melts.

The maintaining of the chromaticity for the sharp cutoff glasses in yellow, orange, and red is more difficult. With these glasses the hue is not entirely dependent on the constituents of the batch, but upon the batch and heat treatment as the ware is formed. The coloring agent forms a colloidal suspension in clear silicates, and the color depends on the number and size of particles. Because of this there is considerable variation from melt to melt, from piece to piece in the same melt, and occasionally a single $6\frac{1}{2}$-in. square will vary. In addition the color may be concentrated on one surface.

It is practically impossible for a glass manufacturer to accept an order for

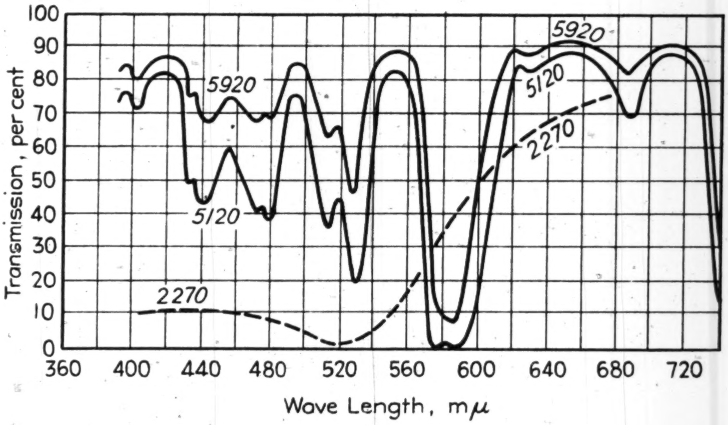


FIG. 5.—Transmission of Didymium Filter.

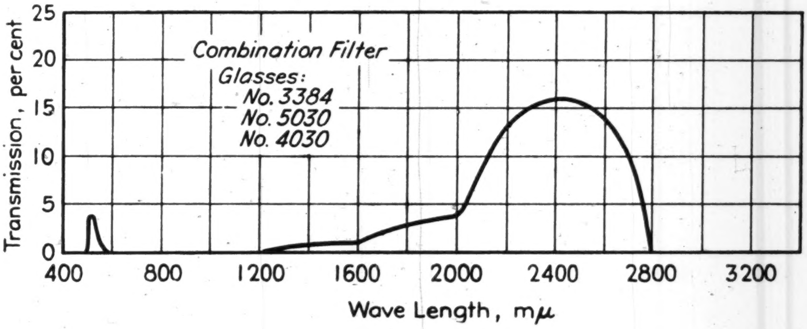


FIG. 6.—Transmission of Narrow Band Filter with Considerable Transmission in the Infrared.

colored glass of definite hue at a definite thickness. Tolerances on thickness or hue must be permitted.

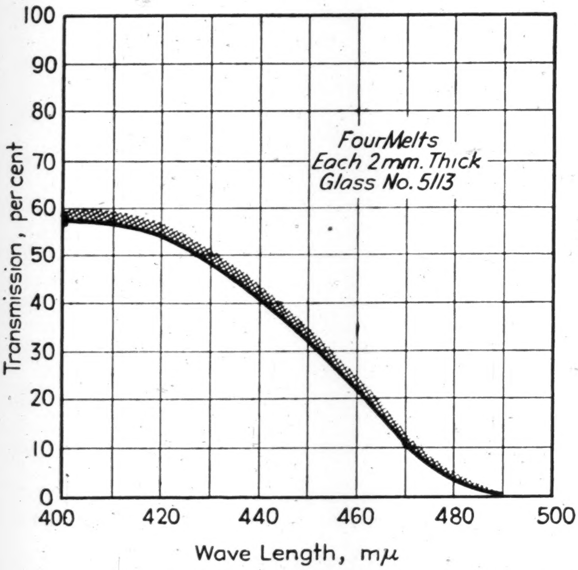


FIG. 7.—Transmission of a Series of Melts All Ground to Same Thickness.

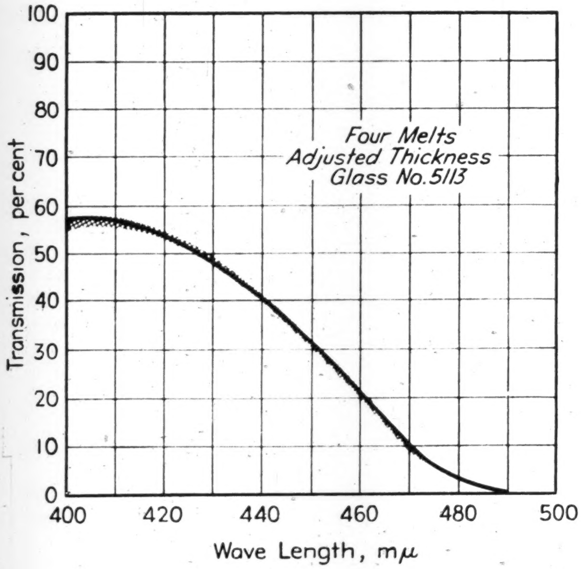


FIG. 8.—Transmission of Same Melts as in Fig. 7, but Corrected for Thickness.

From this outline of a complicated problem, it is hoped to make clear that a colored filter is more than just a piece of glass. It is really a scientific instrument which performs a certain function and to make it perform requires skill, special training, and painstaking care on the part of the manufacturers to obtain the desired results.

SPECTROPHOTOMETERS

By Kasson S. Gibson[1]

Spectrophotometry has a three-fold application. Primarily, it is a research tool in the study of all kinds of materials—a means by which the absorption of radiant energy over a wide range of wave lengths may be measured and correlated with other physical or chemical properties.

A second application is its widespread use in the colorimetric analysis and standardization of a great variety of materials of commerce—glass, dyes, textiles, papers, paints, etc.—in which the color is the inherent property of interest, as in signal glassware, or in which color is an index of other qualities, as in vegetable oils, or in which color is important from the standpoint of sales appeal, as in clothing and household furnishings.

A third application is in chemical analysis, where in many cases the spectrophotometric method is an accurate and rapid means of quantitative analysis greatly superior to other methods. This is the primary concern of this paper.

In the first and third applications there is no logical boundary between ultraviolet, visible, and infrared; and spectrophotometry has by long usage been universally applied to the spectral measurement of absorption, transmission, or reflection from about 200 mμ in the ultraviolet to about 1000 mμ in the infrared. There is, in fact, one spectrophotometer now on the market covering this entire range.

Only in colorimetric work of the type noted in the second application above, does the visible spectrum have a unique significance. Even there, however, the eye is often inadequate as a spectrophotometric receptor because of its low brightness response to the chromatically important blue and violet spectral regions.[2]

The interest in spectrophotometry as an analytical tool in chemical work is evidenced by the papers presented in this symposium. This interest lies mostly in the field of transmission spectrophotometry, that is, in the measurement of the spectral transmission or absorption of transparent solutions. The present paper is accordingly of limited scope. It is not intended to be a general survey of spectrophotometry (**3, 19**).[3] It will deal only briefly with spectral reflection measurements (**9**). It will not include the broad field of infrared spectroradiometry, which has recently been found of such great value in the analysis of high polymers (**23**), nor the field of photographic spectrophotometry (**14, 24**), which has been but little used in analytical work of the type considered here today.

It is also impossible to describe here the numerous instruments or equipment that have been devised for spectrophotometric work by individual investigators over a period of many years; reference can only be made to bibliographies of such work found in other publications (1, 6, 15, 17, 20, 22). It has seemed most useful for the purposes of the present symposium to consider only those instruments which have fairly widespread use among the analytical chemists. The paper will therefore consider principally those visual and photoelectric spectrophotometers which are (or have been until recently) available commercially for transmission measurements in the visible spectrum or in the adjacent regions of the ultraviolet and infrared.

---

[1] Chief, Photometry and Colorimetry Section, National Bureau of Standards, Washington, D. C.

[2] The standard observer and coordinate system for colorimetry established in 1931 by the International Commission on Illumination is defined by spectral distributions extending from 380 to 770 mμ.

[3] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 731.

SPECTROPHOTOMETERS *versus* FILTER PHOTOMETERS

At the National Bureau of Standards we are often asked by some prospective purchaser whether he should obtain a spectrophotometer or a filter photometer. The answer depends on his particular work and circumstances, but it is a question to which certain general answers can be given (18). The spectrophotometer has two important advantages. Within its wave length range there are no restrictions on the wave lengths that may be used, whereas with the filter photometer one is limited to the particular wave length regions isolated by the combinations of filter, photocell, and lamp. With the spectrophotometer, furthermore, the slits can usually be made sufficiently narrow that energy of an effectively definite wave length can be isolated, this wave length being essentially independent of spectral distribution of source and spectral response of photocell and free of modification caused by the spectral selectivity of the material beingmeasured. With the filter photometer, on the other hand, the correct effective wave length of the region isolated is often not known exactly, and this wave length is modified by the material being measured.

The advantages of the filter photometer are in general the practical ones of lower cost, greater portability, and less skill required for operation and maintenance. The spectrophotometer is necessary for fundamental research, analysis, and standardization and is also generally suitable for control work and comparative standardization. The filter photometer is almost certain to be inadequate for fundamental measurements. As an abridged spectrophotometer its usefulness will depend on the number and effectiveness of the isolating filters used. As a control or standardizing instrument its value will depend, among other things, on the optical and electrical stability of its components, and on the degree of spectral similarity between standard and unknown solutions. The widespread use of such instruments indicates that they are of considerable utility for such work (25).

The "fluorescence error" (discussed under "conclusions") may or may not occur to an important extent with filter photometers, depending on the design of the instrument.

AVAILABLE COMMERCIAL SPECTROPHOTOMETERS

While foreign-made instruments may possibly still be available in isolated instances, no attempt has been made to check on this, and no descriptions of such instruments are given in this paper.

Visual Spectrophotometers:

So far as known there are but two makers of visual spectrophotometers in this country at the present time, the Bausch and Lomb Optical Co. (2)[4] and the Gaertner Scientific Corp. (7). In both cases (8) the photometric scale of the instrument is based on the polarization principle as expressed in the relation:

---

[4] It is understood that the Bausch & Lomb spectrophotometer is not at present available commercially.

$$\frac{I}{I_o} = \frac{\tan^2 \alpha}{\tan^2 \alpha_o}$$

where:

α_o = angle of match with both beams blank (or containing similar cells filled with solvent),

α = angle of match when solution and solvent are placed in the appropriate beams, and

$\frac{I}{I_o}$ = transmittancy.

Both the Bausch and Lomb and the Gaertner spectrophotometers are direct-reading in wave length and in transmittancy and $\log_{10}$ transmittancy. As with all spectrophotometers, however, these scales should be carefully checked—the wave length scale by the use of a mercury, helium, or other source having a few lines of known wave length appropriately spaced throughout the visible spectrum, the photometric scale by appropriate standardized filters or by measurements on solutions known to conform to Beer's law.

Reflection measurements can be made by means of special illumination spheres. The illumination is approximately diffused and the light is taken for measurement approximately at right angles to the surfaces of sample and standard.

Special devices worthy of note are the wave length scale of the Gaertner spectrophotometer, which permits precise wave length settings in the long-wave part of the visible spectrum, and auxiliary equipment on the Bausch and Lomb spectrophotometer whereby the lengths of solutions may be conveniently varied during measurement without changing cells.

Photoelectric Spectrophotometers:

The four instruments to be described differ greatly in design and operation, and will accordingly be considered separately. They are listed in alphabetical order. The optical features of these spectrophotometers will be emphasized, and the electrical circuits given only secondary consideration.

Beckman Quartz Spectrophotometer.—The Beckman spectrophotometer has been described in detail in a paper (4) published in the Journal of the Optical Society of America and most of these details will not be repeated here. It is a quartz spectrophotometer with a range from approximately 210 mμ with a hydrogen-arc source and "blue-sensitive" photocell to approximately 1050 mμ with an incandescent source and "red-sensitive" photocell. The exact long-wave limit of usefulness probably varies with the individual photocell. The wavelength scale of the instrument is extended to 2000 mμ, but it should be noted that measurements made beyond the limit of adequate sensitivity of the photocell (on the instrument in the Photometry and Colorimetry Section of the National Bureau of Standards this is at 1050 mμ, approximately) are measurements largely or entirely with stray energy and may therefore be greatly in error.

However, through the region below this wave length limit this instrument is relatively free from stray radiant energy for a single-dispersion instrument. This is because of the small number of optical surfaces between the entrance and exit slits, together with the dust-excluding chamber in which the internal optics of the instrument are inclosed. A stray-light filter is provided for the region below 400 mμ for use with the incandescent source.

In measuring the transmission of a glass filter (against the blank beam) the results will be slightly high because of multiple reflections between the glass and the quartz plate (readily removable) over the exit slit (and the ultraviolet stray-light filter when used). Serious errors may be caused if the sample is wedge-shaped and the transmitted beam thereby diverted to a different region of the photocell.

The sensitivity is such that extremely narrow slits can be used and the spectral purity of the energy used is high. For materials that are highly selective, therefore, this instrument should afford a more accurate spectrophotometric analysis than any of the other photoelectric instruments described.

The photometric scale is based on electrical rather than optical principles. The photoelectric current from the irradiated cell produces across the phototube load resistor a voltage drop which is balanced by a potentiometer. While making this null setting, any imbalance is amplified electronically and is indicated by a galvanometer on the instrument. Accuracy of the photometric scale depends on linearity of the irradiation current relationship. Since vacuum photocells are used, the relation should hold closely.

Reflection measurements can be made with the Beckman spectrophotometer by means of auxiliary equipment which can be purchased separately. The optical arrangement is such that the spectral energy is incident approximately at right angles to the surface, and the energy diffusely reflected at approximately 45 deg. in all directions is directed onto the photocell for measurement. The specular component of the reflected energy is therefore effectively excluded in this instrument. Slit widths need not exceed 10 mμ in the visible spectrum and in the green are considerably less.

Cenco-Sheard Spectrophotometer.—This instrument, known as the spectrophotelometer (21), is a grating instrument using a barrier-layer photocell as the detector. The spectral range is given as 325 to 750 mμ. Below 390 and above 650 mμ, stray radiant energy is largely eliminated by the use of appropriate filters.

Transmissions are determined by a ratio-of-deflections method with a box-type galvanometer. The photometric scale thus depends on the linearity of response of the barrier-cell current with incident radiant flux, and data are given indicating that the cell gives a closely linear response at these relatively low values of incident radiant flux.

Four exit slits of nominal width equivalent to 2.5, 5, 10, and 20 mμ of spectrum are supplied with the instrument. Checking of the wave length scale can be made with special ease by means of a suitably placed, permanently mounted eyepiece. One can avoid the "fluorescence error" (discussed under "Conclusions") on this spectrophotometer by mounting the samples in front of the entrance slit, although special equipment for this purpose does not come with the instrument.

The instrument is not designed for reflection measurements.

Coleman Spectrophotometers.—Three spectrophotometers (5) are made by the Coleman Electric Co.; (*1*) the "double monochromator" spectrophotometer (Models 10 and 10s), (*2*) the "universal" spectrophotometer (Model 11) designed especially for chemical analysis in the industrial laboratory, and (*3*) the "junior clinical" spectrophotometer (Model 6) designed solely for use in clinical laboratories. Dispersion in all of these instruments is secured by means of replica gratings. They are not designed for reflection measurements.

In the double-monochromator spectrophotometer, stray radiant energy is effectively eliminated by the two dispersions provided in the instrument. That is, the stray energy present in the spectrum after dispersion by the first grating is itself dispersed by the second grating, so that the spectral region transmitted by the exit slit is relatively free of such stray energy. Slits passing nominally 30 mμ of spectrum are supplied with the Model 10 instrument and slits passing 5, $7\frac{1}{2}$, 15, and 30 mμ are supplied with the Model 10S instrument.

An electron-emission type of phototube is used as detector, and the wave length range is given as 350 to 1000 mμ. The photometric scale is electrical in nature, and its accuracy will depend on the linearity of response of the photoelectric current to the incident radiant flux. The photoelectric current from the irradiated cell produces across the phototube load resistor a voltage drop which is balanced by a potentiometer. While making this null setting, any imbalance is amplified electronically and is indicated by an auxiliary meter accompanying the instrument.

The universal spectrophotometer is a single-grating instrument with barrier-layer cell as detector. Its wave length range is given as 300 to 800 mμ, and slits passing a spectral region of 35 mμ are installed in the instrument. Special filters are supplied to assist in the reduction of stray energy. Transmissions are given by the ratio-of-deflections method, values being read off a scale on the instrument. Accuracy is thus dependent on the linearity of the radiant flux-current relationship of the barrier-layer cell.

The junior-clinical spectrophotometer is similar to the universal instrument, but the wave length range is restricted to the region from 400 to 700 mμ. It was specifically designed for clinical analysis and is offered for sale only for such use.

It should be noted that the universal and the clinical spectrophotometers are both designed for specific purposes and should not be expected to equal the performance of more elaborate spectrophotometers in measurements of the type for which these special-purpose instruments were not designed.

General Electric Recording Spectrophotometer.—This photoelectric spectrophotometer has been described in various publications (**10, 12, 13, 16**). It is designed for both transmission and reflection measurements and records the spectral transmission or reflection curves as a function of wave length over the visible spectrum from 400 to 700 or 750 mμ. (It is possible to extend these curves to about 1000 mμ by special adjustments of the instrument, although not conveniently at constant spectrum slit width.) A "x5" cam is regularly supplied with the instrument, and "log" and "log log" cams can be supplied if requested.

The usual width of spectrum transmitted by the slits is approximately 10 mμ, although instruments having slits passing nominally 4, 5, or 8 mμ have been made.

Stray spectral energy has been effectively excluded in this instrument by means of the second prismatic dispersion. The photometric scale is optical and based on the same $\tan^2 \alpha$ relation as noted above for the visual instruments. Accuracy of results is accordingly not dependent on linearity of photocell radiant flux-current relationship.

In reflection measurements the spectral energy is incident normally or nearly so, and the energy diffusely reflected in nearly all directions is accepted for measurement. In the older instruments the specular component is directed back onto the entrance aperture and was partly included in and partly excluded from the measurement. In the more recent design the specular component may be completely included in the measurements or, in the case of a plane polished surface, effectively excluded from the measurements.

CONCLUSIONS

Visual spectrophotometers (8) can hardly compete with photoelectric spectrophotometers in speed and precision, but their fundamental accuracy is usually high. Their useful range is limited at the longer and shorter wave lengths by the decreasing brightness sensitivity of the eye. This range can be increased at the short-wave end by incorporating a strong mercury arc as an alternative source, making photometric measurements possible at 435.8 and 404.7 mμ, and at both ends by designing the source so as to give the highest feasible brightness. Appropriate filters should be used in these end regions to eliminate stray light from the brighter portions of the spectrum; otherwise serious errors may result.

In considering both visual and photoelectric spectrophotometers, it is appropriate to repeat what has been emphasized many times before—that accuracy and reproducibility are not the same thing. No instrument is free from error under certain circumstances, this depending greatly on the sample being measured: and all of them can get out of adjustment. The great danger is that they may be reproducing readings closely, but the readings may be seriously in error. Only thorough knowledge of the principles involved, continued checking of the wave length and photometric scales, and great care and watchfulness at all times, will insure continued accuracy in results.

The four photoelectric spectrophotometers considered above have two important things in common. In discussing these and the other items already noted, we do not mean to be unduly critical. Two of the four instruments are in almost daily use in the Photometry and Colorimetry Section of the National Bureau of Standards and are giving excellent service. Standardization and testing work is being done of a nature and at a rate wholly impossible with the older instruments. But a paper of this nature is most helpful if it emphasizes possible sources of error and indicates methods of avoiding them.

The first common feature of these four spectrophotometers is that they "eliminate the human eye," in the sense that the eye is replaced by a photocell as the detector of the radiant energy. The eye is of course still used to set scales, to read scales, or to read curves, and there is even greater need for some one to be available who is thoroughly familiar with the optical and electrical principles involved and for operators who will exercise eternal care in the use of the instrument.

The second feature common to these four instruments is that as designed they are all subject to the "fluorescence error" (11) to an important extent. This error relates to the positioning of the sample and has arisen in the following way:

In most of the older spectrophotometers the sample was placed in some position in front of the entrance slit; the radiant energy transmitted or reflected by the sample and standard was then dispersed within the instrument and that part isolated by the exit slit was used in the measurement. The great defect of this type of illumination is that the sample is irradiated by energy of the full spectral range (ultraviolet, visible, and infrared) emitted by the source, and as a result the sample may become so heated as to be temporarily or permanently changed in transmission or reflection before the measurements are completed, or even started.

Largely to remedy this defect, the more recent spectrophotometers have dispersed the radiant energy and isolated a small spectral range before the energy of that wave length is incident upon the sample. This eliminates the excessive heating effects, but may introduce an important error if the sample is activated to fluorescence by the radiant energy falling upon the sample. For example, with some samples, strong reddish fluorescence may be excited by green radiant energy. If the photoelectric cell is highly sensitive to red energy, as is often the case, the photoelectric current evoked by this undispersed red fluorescent energy is added to that produced by the normally transmitted green energy and the spectral transmission values in the green spectral region will be erroneously high. Since the activating region is usually one of strong absorption, the resulting error may be of considerable importance to the analytical chemist.

In the type of colorimetric standardization involved, for example, with dyed textile materials, which are often fluorescent, the situation is still more complicated. In such work the spectrophotometric curve over the whole visible spectrum is usually taken as the fundamental basis for the colorimetric standardization of the sample. If the sample is fluorescent, however, the spectrophotometric values obtained on any one of these four instruments (either transmission or reflection) will not only be too high in the activating spectral region but will also be too low in the fluorescent spectral region, so that large errors will result in the final colorimetric specification. Even on the older instruments, where the fluorescent energy is dispersed, along with the transmitted or reflected energy, true colorimetric specifications will result only for the illuminant used to irradiate the sample. If one wishes the specification for daylight illuminant he must irradiate the sample by daylight, the ultraviolet part of the irradiation being as important to consider as the visible part.

In the spectrophotometry of fluorescent materials, accordingly, the spectral distribution of the energy incident on the sample has an effect on the results obtained, the importance of which depends on the kind and degree of the fluorescence and the use made of the data. This is the only case wherein the spectral energy distribution of the illuminant will affect the results obtained by otherwise accurate spectrophotometry.

REFERENCES

(1) S. E. Q. Ashley, "Spectrophotometric Methods in Modern Analytical Chemistry," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 11, p. 72 (1939).

(2) Bausch and Lomb Optical Co., Rochester, N. Y., advertising circulars.

(3) W. R. Brode, "Chemical Spectroscopy," John Wiley and Sons, Inc., New York, N. Y., p. 150 (1943).

(4) H. H. Cary, and A. O. Beckman, "A Quartz Photoelectric Spectrophotometer," *Journal Opt. Soc. Am.*, Vol. 31, p. 682 (1941). Also advertising circulars of the National Technical Laboratories, Pasadena, Calif.

(5) Coleman Electric Co., Chicago, Ill., advertising circulars.

(6) D. L. Drabkin, "Photometry and Spectrophotometry," *Medical Physics*, edited by Otto Glasser, The Year Book Publishers, Inc., Chicago, Ill., p. 967 (1944).

(7) Gaertner Scientific Corp., Chicago, Ill., advertising circulars.

(8) K. S. Gibson, "Visual Spectrophotometry," *Journal Opt. Soc. Am.*, Vol. 24, p. 234 (1934). See also in "Measurement of Radiant Energy," edited by W. E. Forsythe McGraw-Hill Book Co., Inc., New York and London (1937).

(9) K. S. Gibson, "Survey of Spectrophotometers," *Tech. Assoc. Papers* (T.A.P.P.I.), Vol. 23, pp. 475–480 (1940). Also published in *Paper Trade Journal*, Tech. Sec., Vol. 111, p. 135 (1940).

(10) K. S. Gibson, and H. J. Keegan, "Calibration and Operation of the General Electric Recording Spectrophotometer of the National Bureau of Standards," *Journal Opt. Soc. Am.*, Vol. 28, p. 372 (1938).

(11) K. S. Gibson, and H. J. Keegan, "On the Magnitude of the Error Resulting from Fluorescence in Spectrophotometric Measurements," *Journal Opt. Soc. Am.*, Vol. 28, p. 180 (1938).

(12) A. C. Hardy, "A New Recording Spectrophotometer," *Journal Opt. Soc. Am.*, Vol. 25, p. 305 (1935).

(13) A. C. Hardy, "History of the Design of the Recording Spectrophotometer," *Journal Opt. Soc. Am.*, Vol. 28, p. 360 (1938).

(14) G. R. Harrison, "Current Advances in Photographic Photometry," *Journal Opt. Soc. Am.*, Vol. 24, p. 59 (1934).

(15) M. G. Mellon, "The Role of Spectrophotometry in Colorimetry," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 9, p. 51 (1937).

(16) J. L. Michaelson, "Construction of the General Electric Recording Spectrophotometer," *Journal Opt. Soc. Am.*, Vol. 28, p. 365 (1938).

(17) R. H. Müller, "Photoelectric Methods in Analytical Chemistry," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 11, p. 1 (1939).

(18) National Bureau of Standards, Photoelectric Colorimeters, *Letter Circular LC 545* (1939).

(19) Optical Society of America Progress Committee for 1922–1923. K. S. Gibson, Chairman, Report on Spectrophotometry, *Journal Opt. Soc. Am.* and *Rev. Sci. Inst.* Vol. 10, p. 169 (1925).

(20) R. Sewig, "Lichtelektrische Spectralphotometer," Archiv. für Technisches Messen, *Journal*, Vols. 385–391, p. 69 (1938).

(21) C. Sheard and M. N. States, "A Concave Grating Photoelectric Spectrophotometer," *Journal Opt. Soc. Am.*, Vol. 31, p. 64 (1941) Also advertising circulars of the Central Scientific Co., Chicago, Ill.

(22) J. W. Stillman, Bibliography of Photoelectric Spectrophotometric Methods of Analysis for Inorganic Ions (Covering the Analytical Edition of *Industrial and Engineering Chemistry*, Vol. 1 to Vol. 16, No. 6, and the *Analyst*, Vol. 62 to Vol. 69, No. 5 (1943). See p. 740.

(23) "Symposium on Infra-red and Organic Chemistry," *Journal Opt. Soc. Am.*, Vol. 34, June, 1944, pp. 346–349.

(24) F. Twyman, and C. B. Allsopp, "The Practice of Absorption Spectrophotometry with Hilger Instruments," Adam Hilger, Ltd., London, England (1934).

(25) J. A. Van den Akker, "A Survey of Abridged Spectrophotometers," *Tech. Assoc. Papers* (T.A.P.P.I.), Vol. 23, pp. 480–489 (1940). Also published in *Paper Trade Journal*, Tech. Sec. Vol. 111, p. 140 (1940).

THE CHEMISTRY IN COLORIMETRY

By M. G. Mellon[1]

In its broadest applications colorimetry includes all procedures that have as their objective the evaluation of materials by means of some property related to color. Such measurements divide themselves into those dealing with the determination of color as color, and with the determination of the presence and/or the amount of some desired constituent. Since the 1941 A.S.T.M. Symposium on Color (**1**)[2] was devoted to the former group, the present discussion is confined to what may be considered as chemical analysis.

Strictly speaking, colorimetry is measurement, and therefore involves no chemistry. Actually, in the determination of a desired constituent, one seldom finds the system originally in condition for measurement. The determination of aluminum in a magnesium-base alloy is an example. First, the sample must be dissolved. Then the aluminum ion, since its solution is colorless, must be converted into a colored system having suitable colorimetric properties. In case any other constituent interferes, one must compensate its effect, remove the constituent, or prevent its functioning through some appropriate chemical reaction. These transformations constitute the chemical portion of the analytical procedure.

The coverage of the present symposium is fairly well divided between instruments for colorimetry and their application to important industrial materials. Analysts now have a wide variety of such instruments, ranging from matched test tubes to the most elaborate photoelectric spectrophotometers, such as that containing a Müller-Hilger double monochromator. Previous publications (**11**), together with the papers on instrumentation on this program, deal with this part of the subject.

On the assumption that one has the means of measurement best suited to his requirements, the remaining problem is to prepare the sample for measurement. The objective of this paper is to consider briefly some of the chemical problems involved. The most important of these are the characteristics of colored solutions, the selection of color-forming reactions, and the provision for eliminating interferences.

Desirable Colorimetric Properties

Occasionally the system to be examined is already in a form suitable for measurement without making any chemical transformations; but since this is so rarely the case, we shall assume that such treatment is necessary. Also we shall assume that the measurement is to be made on a liquid solution containing the desired constituent, or another constituent which is chemically equivalent.

Before considering the possibilities of preparing such colored systems, we may note the general requirements which they should meet to make them most satisfactory for use. Relatively few solutions, of course, approach the ideal of meeting all these requirements. Knowing the requirements, the wise analyst selects from the systems available the one best adapted to his problem, and then he uses it with the knowledge of what the deficiencies are.

---

[1] Professor of Analytical Chemistry, Department of Chemistry, Purdue University, Lafayette, Ind.

[2] The boldface numbers in parentheses refer to the list of references appended to this paper, see p. 739.

In general, any solution destined for colorimetric measurement should possess at least the following properties:

1. Be intensely colored—so that small amounts of the unknown may be determined. In many cases flexibility may be achieved through preliminary dilution or concentration of the desired constituent. Also different color-forming reagents, if used, may be found for application to different ranges of concentration. Some solutions are subject to color intensification by altering the nature of the solvent system, as in the use of acetone when determining iron as the thiocyanate.

2. Be stable—so that the determination need not be completed rapidly before fading would vitiate the results, and so that similarly prepared standards for visual matching will be reasonably permanent. Instability is the result of several kinds of action, such as air oxidation and photochemical irradiation. Control of the operative factor often enables one to prepare a measurable system.

3. Be little affected by pH change—so that close control of this factor is unnecessary. If pH changes do affect the color, it is desirable to be able to secure a measurable system by adding an approximate amount of some common acid or base, or a compound such as ammonium acetate or borax. With very sensitive systems, one may have to resort to close buffering, usually checked best by means of a glass electrode.

4. Have a color that permits a spectral region between 475 and 625 mμ to be isolated for measurement, if visual means are used—so that advantage may be taken of the maximum position of the relative luminosity curve. With photoelectric instruments, the region of maximum sensitivity will depend upon the photocell.

5. Have the system possess a small temperature coefficient (and also have any necessary color formation proceed at room temperature)—so that the procedure may be as simple as possible.

6. Have the colorimetric characteristics reasonably close to those of the "matching" permanent standards, if such are used—so that comparisons will be valid under any lighting conditions.

7. Conform to Beer's law—so that any type of method of measurement may be used.

In addition to these general requirements, systems resulting from reactions with color-forming reagents should meet, as far as possible, the following requirements:

1. Develop the color quickly—so that one need not wait for a reaction taking much time for its completion.

2. Form the color with a reagent that does not itself show selective light absorption—so that excess reagent will not complicate the method. Use of a colored reagent gives a system whose total color depends upon the excess reagent added.

3. Have a color reaction that is free from interference by substances other than the unknown—so that the color formed will depend only upon the desired constituent present. Ideally, we want a specific reaction. Practically, one of high selectivity is the best we achieve.

4. Have the intensity of the color produced independent of the amount of the color-forming reagent, provided an excess is used—so that the amount of the desired constituent may be assumed to be proportional to the intensity of color (provided Beer's law applies). If the reaction is not stoichiometric, use of

a large excess of reagent may yield reasonably satisfactory results.

5. Have the nature of the color-forming reaction known—so that reproducible conditions may be maintained if the process is susceptible to the effects of variable factors.

6. Use the same solvent for the unknown and for any color-forming reagent —so that excess reagent will not itself precipitate nor cause precipitation of high concentrations of diverse ions.

7. Require no special treatment for the colored solution, such as extraction of the colored compound with an organic solvent—so that the procedure may be as simple as possible.

8. Be independent of the order of mixing reagents—so that the routine of operations is not critical.

THE COLORED SYSTEM

Colorimetric measurements are applicable, of course, to gases, liquids, and solids. In analyzing gases one may find a naturally colored constituent, such as nitrogen dioxide, but such instances are rare. Somewhat more frequently liquid samples may contain a desired constituent in a suitably colored form. In the great majority of cases, however, the sample is a solid. Usually it must be dissolved, although a volatilization reaction may effect the separation of a constituent which can then be converted into a colored system. Unless volatilization is applicable, dissolution is the alternative. The latter operation is so well known in analytical work that it need not be considered here. Measurement may be practicable on the solution as such, particularly in the case of organic compounds; but much more frequently a measurable color must be developed by means of some chemical reaction.

Very useful compilations of what has been done in this direction are contained in the treatises by Yoe (**18**), and by Snell and Snell (**14**). The later books by Feigl (**4**), Mellan (**9**), von Stein (**16**), and Yoe and Sarver (**19**) summarize the general use of organic compounds as analytical reagents, including the formation of soluble, colored systems. The papers by Diehl (**3**), Feigl (**5**), Haendler and Geyer (**6**), and Sarver (**13**) help to systematize our knowledge of the way in which the organic compounds react, particularly in the formation of chelate ring structures. Sandell's new book (**12**) covers the use of selected reagents for the determination of the metals.

It seems to be desirable to have a general outline of the kinds of chemical reactions that have been found useful in developing colors suitable for colorimetric measurement. With it one should be helped, not only in keeping in mind what has worked, but also in selecting possible new reagents. In extrapolating past experience, however, we must be careful not to leave the laboratory long to theorize on what we think should happen with an untried reagent. Thus, certain cyclic nitrogen compounds, such as 2,2′-bipyridyl, are excellent reagents for ferrous iron; but some closely related derivatives, containing the same chelating group, do not work. Incidentally, we are interested both in systems posessing color, and in those which will fluoresce characteristically under certain conditions.

The accompanying outline (Table I) is the result of an effort to classify important means of securing colored solutions. It seemed convenient to subdivide the desired constituents into inorganic and organic groups, and then, as far as possible, to consider the reactions in terms of elements, compounds, and ions. A characteristic example is given for each type of colored constituent or reaction listed.

It will be noted that no distinction is made between reactions yielding solutions and those forming precipitates. In fact, precipitation may be necessary to effect the desired color formation. The material is then brought into solution, by means of an appropriate solvent, to render the system measurable. Thus, potassium is precipitated as the dipicrylaminate, filtered, and dissolved in acetone. If simple dissolution of the precipitate does not yield a satisfactory colored system, it may be possible to enhance or improve the color by additional

TABLE I.—CLASSIFICATION OF MEANS OF SECURING COLORED SOLUTIONS FOR COLORIMETRIC ANALYSES.

INORGANIC CONSTITUENTS

- A. Colored as such:
    - 1. Elements
      $2\ Br^- + Cl_2 \rightarrow Br_2$
    - 2. Compounds
      N_2O_4 in gases
    - 3. Ions
      MnO_4^-, Cr^{+++}, $Cr_2O_7^{--}$
- B. Colorless (color must be developed):
    - 1. Elements
      Cl_2 in water + *o*-tolidine → color
    - 2. Compounds
      $H_2O_2 + MoO_4^{--} \rightarrow$ color
    - 3. Ions:
        - (*a*) Inorganic reagents:
            - (*1*) Oxidation
              $Mn^{++} + IO_4^- \rightarrow MnO_4^-$
            - (*2*) Reduction:
              Directly
              $2\ Au^+ + SnCl_4^{--} \rightarrow$ colloidal gold; $H_3[P(Mo_3O_{10})_4] + SnCl_4^{--} \rightarrow$ Mo-blue
              Indirectly
              $Ca^{++} \rightarrow CaC_2O_4 \rightarrow Ca_3(PO_4)_2 \rightarrow H_3[P(Mo_3O_{10})_4] \rightarrow$ Mo-blue
            - (*3*) Complexation:
              Cations
              $Cu^{++} + 4\ NH_3 \rightarrow Cu(NH_3)_4^{++}$
              Anions
              $Co^{++} + 4\ NCS^- \rightarrow Co(NCS)_4^{--}$
            - (*4*) Decolorization
              $Fe(NCS)_6^{---} + 6\ F^- \rightarrow FeF_6^{---}$
        - (*b*) Organic reagents:
            - (*1*) Chromophoric transformation
              H^+ + pH indicator → color change
            - (*2*) Salt formation
              HNO_3 + phenol-2,4-disulfonic acid + KOH → color
            - (*3*) Coupling
              HNO_2 + sulfanilic acid + α-naphthylamine → color
            - (*4*) Adsorption
              $O_2 + 2\ I^-$ + starch → color; Al^{+++} + quinalizarin → lake
            - (*5*) Oxidation
              Cl_2 + 3,3′-dimethylbenzidine → color
            - (*6*) Reduction
              $H_3[P(Mo_3O_{10})_4]$ + hydroquinone → Mo-blue
            - (*7*) Fluorescing formation
              Al^{+++} + morin → fluorescing system
            - (*8*) Chelation:
              Two coordinate bonds
              Fe^{++} + 2,2′-bipyridyl → color
              One coordinate and one electrovalent bond
              Fe^{+++} + kojic acid → color
              Two electrovalent bonds
              Ti^{++++} + maleic acid → color

ORGANIC CONSTITUENTS

A. Colored as such,
    Carotene
B. Colorless (color must be developed):
    1. Oxidation
        Aniline + $PbO_2 \rightarrow$ color
    2. Reduction:
        (*a*) Directly
            Ascorbic acid + methylene blue → fading
        (*b*) Indirectly
            Organic peroxides + $Fe^{++} \rightarrow Fe^{+++}$; $Fe^{+++} + 6NCS^{-} \rightarrow Fe(NCS)_6^{---}$
    3. Coupling:
        (*a*) Directly:
            (*1*) Inorganic reagent,
                $C_6H_5OH + TiCl_4 \rightarrow C_6H_5OTiCl_3$
            (*2*) Organic reagent
                C_6H_5OH + sulfanilic acid (diazotized) → color
        (*b*) Indirectly (intermediate compound)
            $C_6H_6 + 2\ HNO_3 \rightarrow$ 1,3-dinitrobenzene; 1,3-dinitrobenzene + acetone → color

reactions. For example, the oxine from precipitated and dissolved oxinates may be coupled with a diazo compound or oxidized by certain heteropoly acids to give colors.

INTERFERENCES

Although freedom from interference by undesired constituents was mentioned as one of the requirements of an ideal color reaction, the analyst often has to deal with difficulties from the presence of interfering constituents. Brief consideration will be given to some of the ways in which the difficulty manifests itself, and to what can be done about it.

Nature of Interference.—Of the various kinds of interference which are recognized, some of the most important should be noted.

The interfering constituent itself may be colored. The effect will depend upon the intensity of the extraneous color, and upon its nature.

Turbidity may develop, or a precipitate form, which will prevent accurate photometric measurement. Thus, 1,10-phenanthroline forms a color with ferrous iron and, at the same time, a precipitate with any mercuric ion present. Another kind of example is the precipitation of aluminum when one makes the solution ammoniacal prior to adding thioglycolic acid to form a color with iron.

The interfering constituent may form a color with the color-forming reagent, as does cobalt with 2,2′,2″-terpyridyl when this compound is used for forming a colored complex with iron.

Some constituents interfere by complexing the desired constituent to form an ion or compound more stable than that resulting from action of the desired constituent with the color-forming reagent.

Occasionally oxidation or reduction converts an ion into a form unsatisfactory for reaction with the color-forming reagent. Since 2,2′-bipyridyl reacts with ferrous iron, and thiocyanate with ferric iron, it is necessary in the respective cases to have the iron in the required valence state.

Another kind of difficulty results from reaction of the interfering constituent with the colored system, causing it to fade or lose its color entirely. Many reductants affect permanganate in this way.

Means of Prevention of Interference.—Since so many colored systems are subject to interference, it behooves the analyst to be alert to the possibilities, and to know what he can do to avoid the difficulty, or to reduce the effects to negligible amount (12).

Undoubtedly, the most widely applicable method of avoiding interference is to follow the Biblical admonition to pluck out the offender. Translated into chemical terms, this means to separate it. Four principal kinds of methods of separation are available: volatilization, precipitation, electrodeposition, and extraction. The general operations, applications, and merits of such processes have been presented elsewhere (10). Sandell (12) and Willard and Diehl (17) emphasize the problem of concentrating and/or separating traces of desired constituents. Suffice it to state here that separation, because of requirements in time, technique, and equipment, is generally an operation of last resort, something to be avoided if possible.

In some methods, such as those involving the formation of certain dithizonates, the color-forming reaction proceeds concomitantly with the separation of the desired constituent into the nonaqueous layer containing the organic reagent.

Fortunately, in many cases actual separation from an interfering constituent need not be made. Avoidance of this undesirable operation is accomplished in several ways, some of the most important of which are noted.

One of the most obvious remedies for interference is to compensate for it. A familiar example is the addition to the standard solution, with which the unknown is to be compared, of an amount of the interfering constituent equal to its concentration in the unknown. Of course, this necessitates knowing the amount of the interference. In using photometers this addition would be made to the solution in the reference beam, or to that used in preparing a calibration curve. In this way one may compensate for impurity or color in reagents. It may be noted, incidentally, that one should not assume without test that what appears to be a colorless solvent is adequate by itself in the reference beam of the spectrophotometer.

When absorptometers are used for measurement, some interfering colors may be excluded by proper selection of filters in a filter photometer or setting of the monochromator in a spectrophotometer. The former possibility has been discussed by Knudson, Meloche, and Juday (7). An example of the latter possibility is shown in the curves for manganese and chromium published by Silverthorn and Curtis (15). According to this work, absorption at 575 mμ is attributed to manganese only. In either case, it is evident that the nature of the curves must be sufficiently different to make such a procedure feasible.

In some cases the interference must be determined and then taken into account in calculating the desired constituent. The paper by Silverthorn and Curtis (15) illustrates the simpler of two general possibilities. To determine the chromium, the transmittancy measurement is made at 450 mμ. Since manganese absorbs at this wave length also, its absorption, as determined from measurement at 575 mμ (where chromium does not interfere), must be subtracted from the total absorption at 450 mμ. A more complicated case, involving solution of simultaneous equations, is illustrated by the work of Comar and Zscheile (2) on mixtures of two chlorophylls. As a general case, values for the concentration of each of n components may be obtained from absorption measurements at n wave lengths, where no two curves coincide or intersect; however, no two wave lengths may be used at which absorption values for two components are in the same proportion.

Since many reactions are affected by the pH of the solution, control of this variable offers a means of avoiding certain kinds of interference. In using

1,10-phenanthroline, for example, the pH should be within a relatively narrow range if beryllium is present. At a pH above 5.5 the hydroxide precipitates, and below 3.0 the metal complexes with the reagent. The many color formations possible with dithizone (8) under carefully controlled pH is a striking example of the effect of this variable.

One of the most important means of avoiding interference is to convert the interfering ion into a soluble complex, inert as far as the color-forming reaction is concerned. This requires a relatively high degree of stability in the complex. Thus, in a mixture of iron and cobalt, the ferric ion may be complexed with pyrophosphate before adding the thiocyanate to form the complex ion $Co(NCS)_4^{--}$. To make most effective use of this procedure, we need a comprehensive compilation of the many complexing possibilities, including tabulation of the relative stabilities of the complexes with both organic and inorganic reagents.

Control of the valence state of an ion, either the desired or interfering constituent, provides in some cases for avoiding interference. Phosphate or fluoride ions, for example, form a complex with ferric iron. In their presence the iron may be reduced to the ferrous state and then complexed with thioglycolic acid to form a suitably colored system. In such a case the reductant itself must not complex the desired constituent, as sodium formate would do with iron.

REFERENCES

(1) "Symposium on Color," Am. Soc. Testing Mats (1941). (Symposium issued as separate publication.)

(2) C. L. Comar, and F. P. Zscheile, "Analysis of Plant Extracts for Chlorophylls *a* and *b* by a Photoelectric Spectrophotometric Method," *Plant Physiol.*, Vol. 17, p. 198 (1942).

(3) Harvey Diehl, "The Chelate Rings," *Chem. Rev.*, Vol. 21, p. 39 (1937).

(4) Fritz Feigl, "Specific and Special Reactions," Nordeman Co., New York, N. Y. (1940).

(5) Fritz Feigl, "Organic Reagents in Inorganic Analysis, *Industrial and Engineering Chemistry*, Anal. Ed. Vol. 8, p. 401 (1936).

(6) H. M. Haendler and B. P. Geyer, "The Classification of Chelating Groups," *Journal*, Am. Chem. Soc., Vol. 60, p. 2813 (1938).

(7) H. W. Knudson, V. W. Meloche, and Chancey Juday, "Colorimetric Analysis of a Two-Component Color System," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 12, p. 715 (1940).

(8) I. M. Kolthoff and E. B. Sandell, "A Quantitative Expression for the Extractability of Metals in the Form of Dithizonates from Aqueous Solutions," *Journal Am. Chem. Soc.*, Vol. 63, p. 1906 (1941).

(9) Ibert Mellan, "Organic Reagents in Inorganic Analysis," Blakiston Co., Philadelphia, Pa. (1941).

(10) M. G. Mellon, "Methods of Quantitative Chemical Analysis," Macmillan Co., New York, N. Y. (1937).

(11) M. G. Mellon, "The Role of Spectrophotometry in Colorimetry," *Industrial and Engineering Chemistry*, Anal. Ed. Vol. 9, p. 51 (1937); The Present Status of Colorimetry, Vol. 11, p. 80 (1939); "Light Absorption Spectrometry," Vol. 17, p. 81 (1945).

(12) E. B. Sandell, "Colorimetric Determination of Traces of Metals," Interscience Publishers, New York, N. Y. (1944).

(13) L. A. Sarver, "Reactive Groups in Organic Reagents and Their Application in Inorganic Analysis," *Journal*, Chem. Education, Vol. 13, p. 511 (1936).

(14) F. D. Snell and C. T. Snell, "Colorimetric Methods of Analysis," D. Van Nostrand Co., New York, N. Y. (1936–1937).

(15) R. W. Silverthorn and J. A. Curtis, "Colorimetry in Metallurgical Analysis," *Metals and Alloys*, Vol. 15, p. 245 (1942).

(16) Paul von Stein, "Organic Reagents in Inorganic Analysis," Chemical Publishing Co., New York, N. Y. (1942).

(17) H. H. Willard and Harvey Diehl, "Advanced Quantitative Analysis," D. Van Nostrand Co., Inc., New York, N. Y. (1943).

(18) J. H. Yoe, "Photometric Methods of Analysis," Vol. I. "Colorimetry," John Wiley and Sons, Inc., New York, N. Y. (1928).

(19) J. H. Yoe and L. A. Sarver, "Organic Analytical Reagents," John Wiley and Sons, Inc., New York, N. Y. (1941).

BIBLIOGRAPHY OF PHOTOELECTRIC SPECTROPHOTOMETRIC METHODS OF ANALYSIS FOR INORGANIC IONS

Covering the Analytical Edition of *Industrial and Engineering Chemistry*, Vol. 1 to Vol. 16, No. 6 and *The Analyst*, Vol. 62 to Vol. 69, No. 5

PREPARED BY J. W. STILLMAN[1]

General

M. Barnard and P. McMichael, "Quantitative Analysis by Mon-Chromatic Transmission," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 2, p. 363 (1930).

H. M. Partridge, "Applications of the Photoelectric Cell to Chemical Analysis and Control," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 2, p. 207 (1930).

B. W. Story and V. A. Kalichevsky, "Photoelectric Colorimeter for Measuring Color Intensities of Liquid Petroleum Products," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 5, p. 214 (1933).

T. R. Hogness, F. P. Zscheile, Jr., and A. E. Sidwell, Jr., "Photoelectric Spectrophotometry," *Journal Phys. Chem.*, Vol. 41, p. 379 (1937).

*M. G. Mellon, "The Role of Spectrophotometry in Colorimetry," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 9, p. 51 (1937).

*S. E. Q. Ashley, "Spectrophotometric Methods in Modern Analytical Chemistry," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 11, p. 72 (1939).

*M. G. Mellon, "Present Status of Colorimetry," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 11, p. 80 (1939).

*R. H. Müller, "Photoelectric Methods in Analytical Chemistry," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 11, p. 1 (1939).

J. S. Owens, "Quantitative Absorption Spectrophotometry. An Internal Control Method," *Industrial Engineering Chemistry*, Anal. Ed. Vol. 11, p. 643 (1939).

R. W. Silverthorn and J. A. Curtis, "Colorimetry in Metallurgical Analysis," *Metals and Alloys*, Vol. 15, pp. 245-248 (1942).

R. H. Hamilton, "Photoelectric Photometry—An Analysis of Errors at High and at Low Absorption," *Industrial and Engineering Chemistry*, Anal Ed., Vol. 16, p. 123 (1944).

*E. B. Sandell, "Determination of Traces of Metals," Interscience Publishing Co., New York, N. Y. (1944).

Aluminum

J. A. Scherrer and W. D. Mogerman, "Improved Method for Determination of Aluminum in Certain Non-Ferrous Materials by Use of Ammonium Aurintricarboxylate," *Journal of Research*, Nat. Bureau of Standards, Vol. 21, No. 1, July, 1938, p. 105 (*RP 1117*); *Chemical Abstracts*, Vol. 32, 6970 (1938).

H. W. Knudson, V. W. Meloche, and C. Juday, "Colorimetric Analysis of a Two-Component Color System (Estimation of Aluminum)," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 12, p. 715 (1940).

G. U. Houghton, "The Determination of Small Amounts of Aluminum in Water by Means of Hematoxylin," *Analyst*, Vol. 68, p. 208 (1943).

N. Strafford and P. F. Wyatt, "The Separation and Determination of Very Small Amounts of Aluminum and Iron in Water," *Analyst*, Vol. 68, p. 319 (1943).

A. L. Olsen, E. A. Gee, and V. McLendon, "Precision and Accuracy of Colorimetric Procedures as Analytical Control Methods. Determination of Aluminum," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 16, p. 169 (1944).

Antimony

W. G. Frederick, "Determination of Small Amounts of Antimony with Rhodamine B," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 13, p. 922 (1941).

Arsenic

H. A. Frediani and B. J. Babler, "Colorimetric Method for Determination of Barium," *In-*

---

* These references are recommended for important information.

[1] Contribution No. 201 from Chemical Department Experimental Station, E. I. du Pont de Nemours and Co., Wilmington, Del.

dustrial and Engineering Chemistry, Anal. Ed., Vol. 11, p. 487 (1939).

A. L. Chaney and H. J. Magnuson, "Colorimetric Microdetermination of Arsenic," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 12, p. 691 (1940).

C. J. Rodden, "Colorimetric Determination of Arsenic in Ferrous and Non-Ferrous Alloys," *Journal of Research*, Nat. Bureau of Standards, Vol. 24, no. 1, January, 1940, p. 7 (*RP 1267*).

M. B. Jacobs and J. Nagles, "Colorimetric Microdetermination of Arsenic," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 14, p. 442 (1942).

E. B. Sandell, "Colorimetric Microdetermination of Arsenic after Evolution as Arsine," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 14, p. 82 (1942).

S. Christow, "Barium—Photometric Determination," *Z. Anal. Chem.*, Vol. 125, pp. 278–286 (1943); *Chemical Abstracts*, Vol. 37, 4321 (1943).

Bismuth

R. G. Robinson, "A Rapid Method for the Determination of Traces of Bismuth in Lead," *Analyst*, Vol. 64, p. 402 (1939).

R. C. Sproull and A. O. Gettler, "Application of a Photoelectric Colorimeter. Determination of Bismuth in Biological Material," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 13, p. 462 (1941).

K. Woldemar Grosheim-Krysko, "Photometric Determination of Bismuth," Z. Anal. Chem., Vol. 121, pp. 399–402 (1941); *Chemical Abstracts*, Vol. 36, 5107 (1942).

Boron

K. C. Berger and E. Gruog, "Boron Determination in Plants and Soils Using the Quinalizarin Reaction," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 11, p. 540 (1939).

J. A. Naftel, "Colorimetric Microdetermination of Boron," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 11, p. 407 (1939).

D. Dickinson, "A New Colorimetric Method for the Determination of Boron," *Analyst*, Vol. 68, p. 106 (1943).

Cadmium

H. Fischer and G. Leopoldi, "Quantitative Determination of Small Amounts of Cadmium with Dithizone," *Microchemica Acta*, Vol. 1, p. 30 (1937); *Analyst*, Vol. 62, p. 499 (1937).

R. Juza and R. Langheim, "Colorimetric Determination of Cadmium as Sulfide," *Z. Anal. Chem.*, Vol. 110, p. 262 (1937); *Analyst*, Vol. 62, p. 824 (1937).

J. Cholak and D. M. Hubbard, "Determination of Cadmium in Biological Material. Spectrographic, Polarographic, and Colorimetric Methods," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 16, p. 333 (1944).

Caesium

E. S. Burksera and R. V. Feldman, "Colorimetric Determination of Caesium," *Zavodskava Lab.*, Vol. 7, p. 166 (1938); *Analyst*, Vol. 63, p. 681 (1938).

Chromium

G. P. Rowland, Jr., "Photoelectric Colorimetry—An Optical Study of Permanganate Ion and of the Chromium-Diphenyl Carbazide System," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 11, p. 442 (1939).

L. Rossi, A. D. Marenzi, and R. Lobo, "Photometric Microdetermination of the Chromate Ion," *Anales farm. Bioquim.*, Vol. 13, pp. 1–8 (1942); *Chemical Abstracts*, Vol. 36, 6442 (1942).

Cobalt

C. P. Sideris, "Colorimetric Microdetermination of Cobalt and Potassium," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 9, p. 145 (1937).

P. L. Hibbard, "Estimation of Copper, Zinc and Cobalt (with Nickel) in Soil Extracts," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 10, p. 615 (1938).

E. B. Sandell and R. W. Perlich, "Determination of Small Amounts of Nickel and Cobalt in Silicate Rocks," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 11, p. 309 (1939).

J. H. Yoe and C. J. Barton, "Colorimetric Determination of Cobalt with beta-Nitroso-alpha-Naphthol," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 12, p. 405 (1940).

G. H. Cartledge and P. M. Nichols, "Determination of Cobalt as Trioxalatocobaltiate," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 13, p. 20 (1941).

A. M. M. Davidson and R. L. Mitchell, "Determination of Cobalt and Chromium in Soils," *Journal*, Soc. Chem. Ind., Vol. 59, p. 232 (1940); *Analyst*, Vol. 66, p. 29 (1941).

K. Dietrich, "Photometric Determination of Cobalt in Steel and in Ferrocobalt," *Metallwirtschaft*, Vol. 30, pp. 600–601 (1941); *Chemical Abstracts*, Vol. 36, 4436 (1942).

G. Cronheim, "Orthonitrosophenol as a New Reagent in Colorimetric Analysis," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 14, p. 445 (1942).

R. J. De Gray and E. P. Rittershausen, "Colorimetric Determination of Cobalt," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 14, pp. 858–859 (1942).

L. Waldbauer and Nell M. Ward, "Determination of Cobalt and Manganese by Photometric Methods," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 14, pp. 727–728 (1942).

F. W. Haywood and A. A. R. Wood, "Photometric Determination of Cobalt in Steels," *Journal*, Soc. Chem. Ind., Vol. 62, p. 37 (1943); *Analyst*, Vol. 68, p. 263 (1943).

W. L. Moss and M. G. Mellon, "Colorimetric Determination of Cobalt with Terpyridyl," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 15, pp. 74–75 (1943).

L. G. Overholser and J. H. Yoe, "Colorimetric Determination of Cobalt with o-Nitrosoresorcinol," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 15, p. 310 (1943).

Copper

J. P. Mehlig, "Spectrophotometric Determination of Copper in Ores and Mattes," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 7, p. 387 (1935).

B. Eisler, K. G. Rosdahl, and H. Theorell, "Photoelectric Micro-Determination of Copper," *Biochem. Z.*, Vol. 285, p. 76 (1936); *Brit. Chem. Abstracts*, p. 1401A (1936).

H. Hahn, R. Juza, and R. Langheim, "Colorimetric Determination of Copper as Ferrocyanide," *Z. Anal. Chem.*, Vol. 110, p. 270 (1937); *Analyst*, Vol. 62, p. 824 (1937).

T. P. Hoar, "The Colorimetric Determination of Copper with Sodium Diethyldithiocarbamate in the Presence of Moderate Amounts of Iron," *Analyst*, Vol. 62, p. 657 (1937).

T. P. Hoar, "The Rapid Determination of Copper in Mild Steel," *Analyst*, Vol. 62, p. 788 (1937).

P. L. Hibbard, "Estimation of Copper, Zinc, and Cobalt (with Nickel) in Soil Extracts," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 10, p. 615 (1938).

G. F. Palfrey, R. H. Hobert, A. F. Benning, and I. W. Dobratz, "Determination of Small Amounts of Copper and Manganese," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 12, p. 94 (1940).

J. H. Yoe and C. J. Barton, "Colorimetric Determination of Copper with Triethanolamine," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 12, p. 456 (1940).

J. G. Breckenridge, R. W. J. Lewis, and L. A. Quick, "2:2′ Diquinolyl as a Reagent for Copper," *Can. J. Research*, Vol. 17B, p. 258 (1939); *Quart. J. Pharm.*, Vol. 13, p. 277 (1940); *Analyst*, Vol. 66, p. 32 (1941).

J. P. Mehlig, "Colorimetric Determination of Copper with Ammonia," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 13, p. 533 (1941).

K. Quandel, "Photometric Determination of Copper in Steel," *Arch. Eisenhuttenw.*, Vol. 14, pp. 601–604 (1941); *Chemical Abstracts*, Vol. 36, 4773 (1942).

L. Gerber, R. I. Claasen, and C. S. Boruff, "Photometric Determination of Copper and Iron in Distilled Liquors," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 14, p. 364 (1942).

C. A. Greenleaf, "Report on Copper," *Journal*, Assoc. Official Agr. Chem., Vol. 25, p. 385 (1942).

E. I. Stearns, "Dye Extremely Sensitive to Copper," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 14, pp. 568–569 (1942).

G. H. Bendix and D. Grabenstetter, "A Dithizone Method for the Rapid Determination of Copper," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 15, p. 649 (1943).

F. W. Haywood and A. A. R. Wood, "The Rapid Photometric Determination of Copper in Ferrous Materials," *Analyst*, Vol. 68, p. 206 (1943).

E. Geiger and H. G. Müller, "Substituted Dithiocarbonic Acid Reagents for Copper," *Helv. Chim. Acta*, Vol. 26, p. 996 (1943); *Analyst*, Vol. 68, p. 289 (1943).

M. L. Moss with M. G. Mellon, "Colorimetric Determination of Copper with 1, 10-Phenanthroline," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 15, p. 116 (1943).

W. S. Levine and H. Seaman, "Electrolytic Determination of Copper in Steel and Cast Iron," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 16, p. 80 (1944).

Fluorine

J. J. Fahey, "Colorimetric Determination of Fluorine with Ferron," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 11, p. 362 (1939).

L. V. Wilcox, "A Photronic Colorimeter and Its Application to the Determination of Fluoride," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 6, p. 167 (1934).

Gallium

E. B. Sandell, "Detection of Gallium by a Fluorescence Reaction with 8-Hydroxyquinoline," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 13, p. 844 (1941).

Germanium

R. E. Kitson and M. G. Mellon, "Colorimetric Determination of Germanium as Molybdigermanic Acid," *Industrial and Engineering Chemistry,* Anal. Ed., Vol. 16, p. 128 (1944).

Hydrogen Ion

R. H. Müller and H. M. Partridge, "Determination of Hydrogen Ion Concentration with Photoelectric Colorimeter," *Industrial and Engineering Chemistry,* Anal. Ed., Vol. 3, p. 169 (1931).

Indium

T. Moeller, "The Chemistry of Indium. A Colorimetric Method for the Estimation of Small Amounts of Indium," *Industrial and Engineering Chemistry,* Anal. Ed., Vol. 15, p. 270 (1943).

Iron

W. D. McFarlane, "Determination of Iron by Titanium Titration and by Alpha Alpha'-Bipyridine Colorimetry," *Industrial and Engineering Chemistry,* Anal. Ed. Vol. 8, p. 124 (1936).

A. R. Rescorla, E. M. Fry, and F. L. Carnahan, "Photometric Determination of Iron in Used Engine Oils," *Industrial and Engineering Chemistry,* Anal. Ed., Vol. 8, p. 242 (1936).

J. P. Mehlig, "A Spectrophotometric Method for the Determination of Iron in Ores," *Industrial and Engineering Chemistry,* Anal. Ed., Vol. 9, p. 162 (1937).

L. G. Saywell and B. B. Cunningham, "Determination of Iron—Colorimetric o-Phenanthroline Method," *Industrial and Engineering Chemistry,* Anal. Ed., Vol. 9, p. 67 (1937).

H. W. Swank and M. G. Mellon, "Determination of Iron with 7-Iodo-8-Hydroxyquinoline-5-Sulfonic Acid (Ferron)," *Industrial and Engineering Chemistry,* Anal. Ed., Vol. 9, p. 406 (1937).

H. W. Winsor, "Intensity and Stability of Ferric Thiocyanate Color," *Industrial and Engineering Chemistry,* Anal. Ed., Vol. 9, p. 453 (1937).

J. H. Yoe and R. T. Hall, "Colorimetric Determination of Ferric Iron with 7-Iodo-8-Hydroxyquinoline-5-Sulfonic Acid," *Journal,* Am. Chemical Soc., Vol. 59, p. 872 (1937); *Analyst,* Vol. 62, p. 574 (1937).

W. B. Fortune with M. G. Mellon, "Determination of Iron with o-Phenanthroline," *Industrial and Engineering Chemistry,* Anal. Ed., Vol. 10, p. 60 (1938).

F. C. Hummel and H. H. Willard, "Determination of Iron in Biological Materials. Use of o-Phenanthroline," *Industrial and Engineering Chemistry,* Anal. Ed., Vol. 10, p. 13 (1938).

J. P. Mehlig, "Colorimetric Determination of Iron with Salicylic Acid," *Industrial and Engineering Chemistry,* Anal. Ed., Vol. 10, p. 136 (1938).

H. W. Swank and M. G. Mellon, "The Determination of Iron with Mercaptoacetic Acid," *Industrial and Engineering Chemistry,* Anal. Ed., Vol. 10, p. 7 (1938).

D. E. Howe and M. G. Mellon, "Colorimetric Determination of Iron with Salicylaldoxime," *Industrial and Engineering Chemistry,* Anal. Ed., Vol. 12, p. 448 (1940).

J. Molland, "Colorimetric Determination of Iron with Some 8-Hydroxyquinoline Derivatives," *Arch. Math. Naturvidenskab,* Vol. 43, pp. 67–184 (1940); *Chem. Zentr.,* (1940) II, pp. 3230–3231; *Chemical Abstracts,* Vol. 36, 6939 (1942).

L. Roelen, "Colorimetric Determination of Iron in Aluminum and Alumina," *Z. Anal. Chem.,* Vol. 117, p. 385 (1939); *Analyst,* Vol. 65, p. 187 (1940).

Y. Volmar and A. Wagner, "Colorimetric Determination of Ferric Iron by Means of Gallic Acid," *Journal Pharm. Chem.,* Vol. 30, p. 364 (1939); *Analyst,* Vol. 65, p. 249 (1940).

M. L. Moss and M. G. Mellon, "Colorimetric Determination of Iron with Kojic Acid," *Industrial and Engineering Chemistry,* Anal. Ed., Vol. 13, p. 612 (1941).

R. S. Pereira, "New Photometric Method for the Estimation of Iron," *Journal Biol. Chem.,* Vol. 137, p. 417 (1941); *Analyst,* Vol. 66, p. 258 (1941).

R. O. Scott, "The Colorimetric Estimation of Iron with Sodium Salicylate," *Analyst,* Vol. 66, p. 142 (1941).

J. T. Woods and M. G. Mellon, "Thiocyanate Method for Iron—A Spectrophotometric Study," *Industrial and Engineering Chemistry,* Anal. Ed., Vol. 13, p. 551 (1941).

G. Cronheim and W. Wink, "Orthonitrosophenol as a New Reagent in Colorimetric Analysis," *Industrial and Engineering Chemistry,* Anal. Ed., Vol. 14, p. 447 (1942).

L. Gerber, R. I. Claassen, and C. S. Boruff, "Photometric Determination of Copper and Iron in Distilled Liquors," *Industrial and Engineering Chemistry,* Anal. Ed., Vol. 14, p. 364 (1942).

Ruth A. Koenig and C. R. Johnson, "Spectrophotometric Determination of Iron. I. Use of Mercaptoacetic Acid," *Journal Biol. Chem.,* Vol. 142, pp. 233–238 (1942); *Chemical Abstracts,* Vol. 36, 2227 (1942).

Jean L. Larner and W. E. Trout, Jr., "Beta-Resorcylic Acid as a Colorimetric Reagent for Ferric Iron," *Virginia J. Sci.*, Vol. 3, No. 1, p. 13 (1942); *Chemical Abstracts*, Vol. 36, 3114 (1942).

J. P. Mehlig and H. R. Hulett, "Spectrophotometric Determination of Iron with o-Phenanthroline," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 14, p. 869 (1942).

M. L. Moss with M. G. Mellon, "Colorimetric Determination of Iron with 2,2′-Bipyridyl and with 2,2′,2″-Terpyridyl," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 14, p. 862 (1942).

C. P. Sideris, "Colorimetric Microdetermination of Iron," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 14, p. 756 (1942).

H. E. Wirth, "Colorimetric Determination of Small Amounts of Metaphosphate and Pyrophosphate. Determination of Iron with Thiocyanate in the Presence of Metaphosphate and Pyrophosphate," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 14, p. 722 (1942).

Lead

C. L. Guettel, "A Photelometric Study of the Lead-Dithizone System at 610 Millimicrons," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 11, p. 639 (1939).

H. Fischer and G. Leopoldi, "Colorimetric Determination of Small Amounts of Lead by Means of Dithizone," *Z. Anal. Chem.*, Vol. 119, p. 161 (1940); *Analyst*, Vol. 65, p. 432 (1940).

T. V. Letonoff, and J. G. Reinhold, "Colorimetric Determination of Lead Chromate by Diphenylcarbazide (in biological materials)," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 12, p. 280 (1940).

F. L. Kozelka and E. F. Kluchesky, "Photoelectric Colorimetric Technique for the Dithizone System," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 13, p. 484 (1941).

T. V. Letonoff, "Colorimetric Determination of Lead by Diphenylcarbazide," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 13, p. 631 (1941).

J. Schultz and M. A. Goldberg, "Photometric Routine Estimation of Traces of Lead by Dithizone. Application to Materials Used in the Manufacture of Cosmetics," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 15, p. 155 (1943).

Magnesium

H. H. Muller-Neugluck, "Rapid Colorimetric Determination of Magnesium with Titanium Yellow," *Wärme*, Vol. 63, pp. 446–450, pp. 457–458 (1940); *Chemical Abstracts*, Vol. 36, 5107 (1942).

W. S. Gillam, "A Photometric Method for the Determination of Magnesium," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 13, p. 499 (1941).

C. P. Sideris, "Colorimetric Microdetermination of Magnesium," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 13, p. 232 (1941).

L. Gerber, R. I. Claassen, and C. S. Boruff, "Estimation of Magnesium with 8-Hydroxyquinoline," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 14, p. 658 (1942).

E. E. Ludwig and C. R. Johnson, "Spectrophotometric Determination of Magnesium by Means of Titan Yellow," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 14, pp. 895–897 (1942).

W. Stross, "Rapid Photometric Determination of Magnesium in Aluminum Alloys," *Analyst*, Vol. 67, p. 317 (1942).

M. E. Weeks and J. R. Todd, "Determination of Magnesium in Plants and Soils. Adaptation of the 8-Hydroxyquinolate Micro Method," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 15, p. 297 (1943).

Manganese

J. P. Mehlig, "Spectrophotometric Determination of Manganese in Steel," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 7, p. 27 (1935).

C. P. Sideris, "Colorimetric Microdetermination of Manganese," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 9, p. 445 (1937).

W. M. Murray, Jr. and S. E. Q. Ashley, "Determination of Manganese, Nickel, and Phosphorus in Iron and Steel," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 10, p. 1 (1938).

J. P. Mehlig, "Colorimetric Determination of Manganese with Periodate," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 11, p. 274 (1939).

G. P. Rowland, Jr., "Photoelectric Colorimetry—An Optical Study of Permanganate Ion and of the Chromium-Diphenyl Carbazide System," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 11, p. 442 (1939).

G. F. Palfrey, R. H. Hobert, A. F. Benning, and I. W. Dobratz, "Determination of Small Amounts of Copper and Manganese," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 12, p. 94 (1940).

C. P. Sideris, "Improvement of Formaldoxime Colorimetric Method for Manganese," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 12, p. 307 (1940).

Mercury

F. W. Laird and Sister Alonza Smith, "Determination of Mercury with s-Diphenylcarbazide," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 10, p. 576 (1938).

H. E. Ballard and C. D. W. Thornton, "Photometric Method for Estimation of Minute Amounts of Mercury," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 13, p. 893 (1941).

Molybdenum

L. C. Hurd and H. O. Allen, "Colorimetric Determination of Molybdenum," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 7, p. 396 (1935).

J. T. Woods and M. G. Mellon, "The Molybdenum Blue Reaction," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 13, p. 760 (1941).

O. T. Boberkova, "Colorimetric Determination of Molybdenum in Ores by Decomposition with Alkali Hydroxide Solutions," *Zavodskaya Lab.*, Vol. 8, p. 324 (1939); *Chem. Zentr.*, (1940) II, p. 2061; *Chemical Abstracts*, Vol. 36, 6436 (1942).

F. S. Grimaldi and R. C. Wells, "Determination of Small Amounts of Molybdenum in Tungsten and Molybdenum Ores," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 15, p. 315 (1943).

E. R. Vance, "Determination of Molybdenum in Steel," *Steel*, Vol. 111, pp. 56 and 58 (1942); *Analyst*, Vol. 68, p. 127 (1943).

M. L. Nichols and L. H. Rogers, "Determination of Small Amounts of Molybdenum in Plants and Soils," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 16, p. 137 (1944).

Nickel

W. M. Murray, Jr. and S. E. Q. Ashley, "Determination of Manganese, Nickel, and Phosphorus in Iron and Steel," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 10, p. 1 (1938).

G. H. Ayres and Francene Smith, "Colorimetric Determination of Nickel as Nickel-Ammonia Complex," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 11, p. 365 (1939).

V. F. Mal'tsev and T. P. Temirenko, "Photoelectric Method of Determining Nickel in Steels and Cast Irons," *Zavodskaya Lab.*, Vol. 9, pp. 386–390 (1940); *Chemical Abstracts*, Vol. 34, 7208 (1940).

J. P. Mehlig, "Colorimetric Determination of Nickel with Ammonia," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 14, p. 289 (1942).

G. R. Makepeace and C. H. Craft, "Colorimetric Determination of Nickel in Steel," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 16, p. 375 (1944).

H. Seaman, "Colorimetric Determination of Nickel in Bronze," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 16, p. 354 (1944).

Osmium

E. B. Sandell, "Colorimetric Determination of Traces of Osmium," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 16, p. 342 (1944).

Palladium

L. G. Overholser and J. H. Yoe, "Colorimetric Determination of Palladium," *Journal*, Am. Chem. Soc., Vol. 63, p. 3224 (1941); *Analyst*, Vol. 67, p. 72 (1942).

Phosphate

R. J. Robinson and H. E. Wirth, "Photometric Investigation of the Ceruleomolybdate Determination of Phosphate in Waters," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 7, p. 147 (1935).

I. Berenblum and E. Chain, "Improved Method for the Colorimetric Determination of Phosphate," *Biochem. J.*, Vol. 32, p. 295 (1938); *Analyst*, Vol. 63, p. 371 (1938).

S. R. Dickinan and R. H. Bray, "Colorimetric Determination of Phosphate," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 12, p. 665 (1945).

L. T. Kurtz, "Colorimetric Determination of Phosphate in Presence of Fluoride," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 14, p. 855 (1942).

L. S. Stoloff, "Colorimetric Method for Phosphates," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 14, p. 636 (1942).

Phosphorus

C. H. Zinzadze, "Colorimetric Methods for the Determination of Phosphorus," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 7, p. 227 (1935).

C. W. Eddy and F. deEds "A Photoelectric Method for the Determination of Phosphorus," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 9, p. 12 (1937).

W. M. Murray, Jr. and S. E. Q. Ashley, "Determination of Manganese, Nickel, and Phosphorus in Iron and Steel," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 10, p. 1 (1938).

P. Goodloe, "Photometric Determination of Added Phosphorus in Oils," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 9, p. 527 (1937).

J. A. Schricker and P. R. Dawson, "Improved Molybdenum Blue Reagents for Determination of Phosphorus and Arsenic," *Journal*, Assoc. Official Agr. Chem., Vol. 22, p. 167 (1939); *Analyst*, Vol. 64, p. 455 (1939).

J. L. Hague and H. A. Bright, "Colorimetric Determination of Phosphorus in Steel and Cast Iron," *Journal Research*, Nat. Bureau of Standards, Vol. 26, No. 5, May, 1941, p. 405 (*RP 1386*); *Chemical Abstracts*, Vol. 35, 5060 (1941).

H. H. Willard and E. J. Center, "Colorimetric Determination of Phosphorus in Iron Ore," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 13, p. 81 (1941).

C. E. Beauchamp, "Colorimetric Determination of Phosphorus," Mem. 15th conf. annual, Asoc. tec. azucar. Cuba 1941, pp. 47–51; *Chemical Abstracts*, Vol. 36, 2499 (1942).

E. J. Center and H. H. Willard, "Colorimetric Determination of Phosphorus in Iron Ore," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 14, p. 287 (1942).

T. D. Fontaine, "Spectrophotometric Determination of Phosphorus," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 14, p. 77 (1942).

G. Gomori, "Phosphorus Determination: Modification for Use with the Photoelectric Colorimeter," *Journal Lab. Clin. Medi.*, Vol. 27, pp. 955–960 (1942); *Chemical Abstracts*, Vol. 36, 3208 (1942).

Ruth A. Koenig and C. R. Johnson, "Colorimetric Determination of Phosphorus in Biological Materials," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 14, p. 155 (1942).

V. D. Konkin, "Rapid Colorimetric Method for the Determination of Phosphorus in Metals in the Presence of Arsenic," *Zavodskaya Lab.*, Vol. 8, pp. 322–324 (1939); *Chem. Zentr.*, 1940, Part II, 1907; *Chemical Abstracts*, Vol. 36, 6942 (1942).

Mildred S. Sherman, "Colorimetric Determination of Phosphorus in Soils," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 14, p. 182 (1942).

C. P. Sideris, "Improvements in the Colorimetric Microdetermination of Phosphorus," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 14, p. 762 (1942).

W. I. M. Holman, "Estimation of Phosphorus by the Molybdenum Blue Method," *Biochem. J.*, Vol. 37, p. 256 (1943); *Analyst*, Vol. 68, p. 346 (1943).

R. E. Kitson and M. G. Mellon, "Colorimetric Determination of Phosphorus as Molybdivanadophosphoric Acid," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 16, p. 379 (1944).

Potassium

E. Amdur, "Photometric Determination of Potassium with Dipicrylamine," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 12, p. 731 (1940).

E. Rauterberg and E. Knippenberg, "Determination of Potassium by Photometric Spectroscopy," *Ernahr. Pflanze.*, Vol. 37, pp. 73–76 (1941); *Chemical Abstracts*, Vol. 36, 4052 (1942).

E. Rauterberg and E. Knippenberg, "Potassium Determination by a Photometric Method," *Bodenkunde u. Pflanzenernahr*, Vol. 20, pp. 364–384 (1940); *Chemical Abstracts*, Vol. 36, 5108 (1942).

C. P. Sideris, "Adaptation of an Indirect Method for Potassium to the Photoelectric Colorimeter," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 14, p. 821 (1942).

I. W. Wander, "Photometric Determination of Potassium," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 14, p. 471 (1942).

E. H. Wood, "Silver Cobaltinitrite Method for Potassium Determination: Adaptation to the Photoelectric Colorimeter," *Journal Lab. Clin. Medi.*, Vol. 27, pp. 960–965 (1942); *Chemical Abstracts*, Vol. 36, 3208 (1942).

A. Eden, "Photometric Estimation of Potassium by a Modification of the Jacobs-Hoffman Method," *Analyst*, Vol. 68, p. 167 (1943).

Rare Earths

C. J. Rodden, "Spectrophotometric Determination of Praseodymium, Neodymium, and Samarium," *Journal of Research*, Nat. Bureau of Standards, Vol. 26, No. 6, June, 1941, p. 557 (*RP 1395*); *Chemical Abstracts*, Vol. 35, 6212 (1941).

C. J. Rodden, "Spectrophotometric Determination of Dysprosium, Holmium, Erbium, Thulium, and Ytterbium," *Journal of Research*, Nat. Bureau of Standards, Vol. 28, No. 3, March, 1942, p. 265 (*RP 1456*); *Analyst*, Vol. 67, p. 277 (1942); *Chemical Abstracts*, Vol. 36, p. 4437 (1942).

Rhenium

L. C. Hurd and B. J. Babler, "The Determination of Rhenium in the Geilmann Reaction," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 8, p. 112 (1936).

L. C. Hurd and C. F. Hiskey, "Determination of Traces of Rhenium in Pyrolusite," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 10, p. 623 (1938).

J. I. Hoffman and G. E. F. Lundell, "Separation and Colorimetric Determination of Rhenium and Molybdenum." *Journal of Research,* Nat. Bureau of Standards, Vol. 23, No. 4, October, 1939, p. 497 (*RP 1248*); *Chemical Abstracts,* Vol. 34, 959 (1940); *Analyst,* Vol. 64, p. 845 (1939).

Silicon

M. C. Schwartz, "Colorimetric Determination of Silica in Boiler Water," *Industrial and Engineering Chemistry,* Anal. Ed., Vol. 6, p. 364 (1934).

H. W. Swank and M. G. Mellon, "Colorimetric Standards for Silica," *Industrial and Engineering Chemistry,* Anal. Ed., Vol. 6, p. 348 (1934).

R. J. Robinson and H. J. Spoor, "Photometric Determination of Silicate in Sea Water," *Industrial and Engineering Chemistry,* Anal. Ed., Vol. 8, p. 455 (1936).

P. Urech, "Colorimetric Estimation of Silica and Its Use in the Metallurgy of Aluminum," *Helv. Chim. Acta,* Vol. 22, p. 1023 (1939); *Analyst,* Vol. 65, p. 131 (1940).

W. H. Hadley, "Silicon: Determination in Aluminum," *Analyst,* Vol. 67, pp. 5–8 (1942).

M. C. Schwartz, "Photometric Determination of Silica in Presence of Phosphates," *Industrial and Engineering Chemistry,* Anal. Ed., Vol. 14, p. 893 (1942).

B. A. Scott, "Colorimetric Determination of Silicon in Aluminum Alloys," *Analyst,* Vol. 67, p. 389 (1942).

A. J. Boyle and V. V. Hughey, "Photometric Estimation of Silicon in Magnesium and Magnesium Alloys," *Industrial and Engineering Chemistry,* Anal. Ed., Vol. 15, p. 618 (1943).

O. P. Case, "Direct Photometric Determination of Silicon in Copper-Base Alloys," *Industrial and Engineering Chemistry,* Anal. Ed., Vol. 16, p. 309 (1944).

W. Stross, "Photometric Determination of Silicon in Aluminum Alloys. Observations on Hadley's Method," *Analyst,* Vol. 69, p. 44 (1944).

Silver

C. G. Makris and R. Menache, "Colorimetric Determination of Silver," *Ann. chim. anal.,* Vol. 22, p. 117 (1940); *Analyst,* Vol. 65, p. 477 (1940).

J. H. Yoe and L. G. Overholzer, "Colorimetric Determination of Silver with 2-thio-5-keto-4-carbethoxy-1-3-dihydropyrimidine," *Industrial and Engineering Chemistry,* Anal. Ed., Vol. 14, p. 148 (1942).

Sodium

W. C. Woelfel, "Colorimetric Determination of Sodium as Uranyl Manganese Sodium Acetate," *Journal Biol. Chem.,* Vol. 125, p. 219 (1938); *Analyst,* Vol. 63, p. 832 (1938).

E. Leva, "Colorimetric Micro Method for the Estimation of Sodium with Manganous Uranyl Acetate," *Journal Biol. Chem.,* Vol. 132, p. 487 (1940); *Analyst,* Vol. 65, p. 316 (1940).

E. A. Arnold and A. R. Pray, "A Colorimetric Method for the Determination of Sodium," *Industrial and Engineering Chemistry,* Anal. Ed., vol. 15, p. 294 (1943).

Tin

R. E. D. Clark, "The Colorimetric Determination of Tin by Means of Toluene 3:4 Dithiol (Dithiol)," *Analyst,* Vol. 62, p. 661 (1937).

I. Baker, M. Miller, and R. S. Gibbs, "Colorimetric Determination of Tin with Silicomolybdate," *Industrial and Engineering Chemistry,* Anal. Ed., Vol. 16, p. 269 (1944).

Titanium

L. Silverman, "Colorimetric Determination of Titanium in Chromium Steels," *Industrial and Engineering Chemistry,* Anal. Ed., Vol. 14 pp. 791–792 (1942).

Tungsten

G. Bogatzki, "Photometric Determination of, Tungsten in Steel," *Z. Anal. Chem.,* Vol. 114, p. 170 (1938); *Analyst,* Vol. 63, p. 913 (1938); *Chemical Abstracts,* Vol. 33, 79 (1939).

N. S. Polvektov, "Colorimetric Determination of Tungsten," *Zavodskaya Lab.,* Vol. 10, pp. 92–93 (1941); *Chemical Abstracts,* Vol. 35, 5059 (1941).

P. V. Faleev, "Colorimetric Determination of Tungsten in Tin-Tungsten-Arsenic Ores," *Zavodskaya Lab.,* Vol. 8, pp. 1174–1175 (1939); *Khim. Referat. Zhur.,* No. 5, p. 71 (1940); *Chemical Abstracts,* Vol. 36, 3747 (1942).

Turbidity

R. T. Balch, "Measurement of Turbidity with a Spectrophotometer," *Industrial and Engineering Chemistry,* Anal. Ed., Vol. 3, p. 124 (1931).

E. T. Bartholomew and E. C. Ray, "Photronic Photoelectric Turbidimeter for Determining Hydrocyanic Acid in Solutions," *Industrial and Engineering Chemistry,* Anal. Ed., Vol. 7, p. 68 (1935).

Vanadium

E. R. Wright and M. G. Mellon, "The Phosphotungstate Method for Vanadium," *Industrial and Engineering Chemistry,* Anal. Ed., Vol. 9, p. 251 (1937).

E. R. Wright and M. G. Mellon, "The Peroxide Method for Vanadium," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 9, p. 375 (1937).

Zinc

P. L. Hibbard, "Estimation of Copper, Zinc, and Cobalt (with Nickel) in Soil Extracts," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 10, p. 615 (1938).

W. L. Lott, "Determination of Zinc. A Colorimetric Micro Method," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 10, p. 335 (1938).

W. L. Lott, "Colorimetric Micro-Determination of Zinc," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 10, p. 335 (1938).

J. Cholak, D. M. Hubbard, and R. E. Burkey, "Determination of Zinc in Biological Material. Photometric and Polarographic Methods Following Extraction with Di-beta-naphthylthiocarbazole," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 15, p. 574 (1943).

Zirconium

W. G. Hayes and E. W. Jones, "Determination of Zirconium in Steel," *Industrial and Engineering Chemistry*, Anal. Ed., Vol. 13, p. 603 (1941).

COLORIMETRIC DETERMINATION OF SILICON IN ALUMINUM ALLOYS

BY J. J. STUMM[1]

Silicon has been determined colorimetrically for many years. The ammonium molybdate method was first suggested by Jolles and Neurath (**5**)[2] in 1898. It depends upon the formation of a yellow heteropoly compound, molybdisilicic acid, the reaction product of ammonium molybdate and silica in the presence of mineral acid (**8**). This has been the standard method for both the Aluminum Company of America (**2**) and the British Aluminum Co. (**1**) for some time. Its use has been limited to small amounts of silicon. In the method used by the Aluminum Company of America, the caustic residue is filtered off. This is a rather difficult filtration, requiring special apparatus, and in the case of high-silicon alloys some silicon remains in the residue. The British Aluminum Co. uses hydrochloric acid to acidify the caustic solution, thereby introducing an iron effect for the higher concentrations of iron. Both methods make only an approximate adjustment of pH concentration.

Hadley, in his first article (**3**), describes the work done in the research laboratories of the British Aluminum Co. In this article he advises the use of nitric rather than hydrochloric acid for the acidification. Nitric acid naturally acts as an oxidant to prevent the formation of the blue reduction product of the molybdisilicic acid. He also provides special means for the dissolution of manganese alloys, and suggests filtration of the caustic solution for the more complicated alloys. Picric acid standards are recommended. In his second paper (**4**), the conditions are adjusted for the use of the Pulfrich photometer using the mercury line at 4358 Å for illumination. Again extreme care is taken in the dissolution of high-manganese alloys and the suggestion is made that the caustic solution be filtered.

In the above methods, only an approximate adjustment is made for the pH concentration. Schwartz (**7**) shows that the transmission values are fairly constant between 0.5 and 2.0 pH. Hadley (**5**) advises that a pH range of 1.1 to 2.0 is best. Knudson-Juday and Meloche (**6**) advise 1.6 to 2.0 pH. We find, as described later, that a constant pH is absolutely necessary. Since the writing of this article, Stross (**9**) has advised 0.7 to 0.8 pH. As with former methods, his obtains only approximations of these values.

It is the purpose of this paper to show how the use of the colorimetric method may be extended to cover all of the alloys of aluminum with approximately the same accuracy obtained in routine gravimetric methods. This has been made possible through present day equipment for precisely measuring the transmission value of a solution, and through careful adjustment of operating conditions. A method by which the silicon content of an alloy can be determined in 30 to 40 min. to an accuracy of 1 per cent of the true figure in terms of amount present is described. The results obtained by this method almost equal those of gravimetric methods which require several hours for the determination.

---

[1] Chief Chemist, William F. Jobbins, Inc., Aurora, Ill.

[2] The boldface numbers in parentheses refer to the reports and papers appearing in the list of references appended to this paper, see p. 753.

Special Equipment:

It was decided that it would be possible to use smaller amounts of material than in the conventional gravimetric methods. This brought up the question of segregation. We are convinced, after using this method in our laboratory for about one year, that 50 to 100 mg. are sufficient for accurate work. It is necessary, of course, that this sample be taken from a thin chill-cast section.

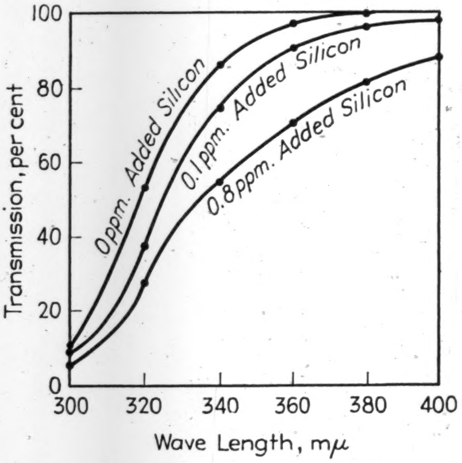


FIG. 1.—Absorption Curves Showing Effect of Varying Amounts of Silicon.

In order to handle 100 mg. of material, a search was made for nickel reaction tubes. Since no source of supply for this article was found, it was decided to use brass centrifuge shields for 50-ml. tubes. These were carefully sanded out to remove any lacquer and to obtain a smooth, polished surface.

A special pipette was fabricated from copper sheet by which to transfer the caustic solution to the reaction vessel with no silicon pick-up. The caustic was mixed in nickel vessels of standard shape and stirred with a copper or nickel rod.

The spectrophotometer used in this work was a Beckman ultraviolet type, and the acidity was controlled by means of the Beckman Laboratory Model pH meter. A motor stirrer with flexible shaft is advisable in connection with the pH adjustment.

Absorption Characteristics:

The absorption curves in Fig. 1 show that there is no definite wave length of maximum absorption. The curve varies in slope and shape, depending upon the amount of silicon present. It was decided that 400 mμ would give about the right absorption for the amount of silicon found in aluminum alloys, namely about 5 ppm. We have found this wave length to be very reproducible over a considerable span of time.

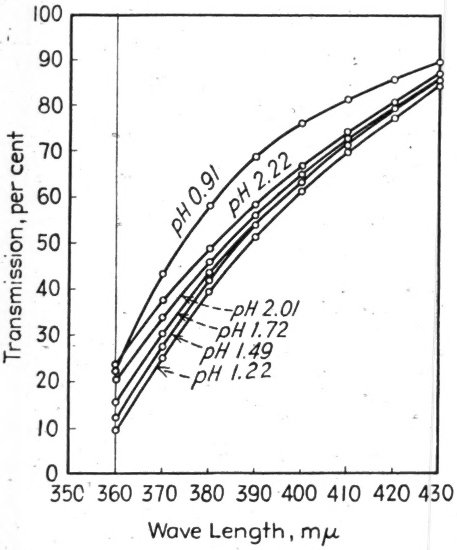


FIG. 2.—Effect of Various pH Values on Color Formation.

Hydrogen Ion Concentration:

In Fig. 2 the shift in the absorption curve is illustrated between pH values of 0.91 to 2.22. The maximum amount of color is developed at 1.22. However, the color is least sensitive to change in acidity at pH of 1.5 to 1.7. There is no change in the curve above 390 mμ at pH values of 1.49 to 1.72. It was therefore decided that this was the ideal range in which to work. In actual practice, we adjust to pH 1.4 and add the molybdate and ammonium peroxidisulphate. This brings the pH to 1.60.

Amount of Reagent:

The color development is not highly sensitive to the amount of molybdate present. A change of from 2 to 5 ml. of 10 per cent ammonium molybdate increased the apparent amount of silicon by 4 per cent. The color development is instantaneous with 5 ml. of molybdate solution, and there is very little fading. Table I shows a set of readings taken at intervals of 2 min. The cell was filled at each reading, thus exposing the remaining portions to light for continuous periods prior to reading.

TABLE I.—EFFECT OF TIME ON COLOR DEVELOPMENT.

Time, min.	Density	Silicon, ppm.
0	0.468	5.22
2	0.468	5.22
4	0.468	5.22
6	0.465	5.19
8	0.463	5.17
10	0.461	5.15
12	0.461	5.15
14	0.460	5.14
16	0.459	5.13
18	0.458	5.12

Temperature Change:

Practically no change was observed in the formation of color between 20 and 30 C., readings changing only from 0.466 to 0.468. This shows that there is an increase in intensity with increase in temperature. The above figures are uncorrected for the volume changes. Such a correction would further increase the apparent increase in intensity. It is sufficient to note that the errors practically balance each other, and little error is made by reading in the range from 20 to 30 C.

Interfering Elements:

Several interfering substances were added as small amounts of solutions of the various nitrates or sulfates. The resulting solution was adjusted for pH and handled exactly as in the subsequent procedure for analysis. The interferences could quite naturally be taken care of, but we have found that this is unnecessary for aluminum alloys. These interferences occur in the form of precipitates. Barium precipitates as the sulfate. Antimony, tin, and bismuth separate out in dilute nitric acid, and large amounts of titanium precipitate with the reagent. The small amounts of these elements that are found in aluminum alloys do not interfere. Aluminum, potassium, and sodium do not interfere in concentrations as high as 250 ppm.

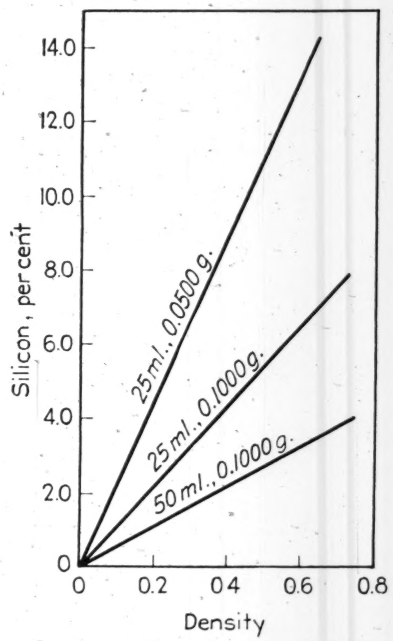


FIG. 3.—Analytical Curves Governing Size of Sample.

No interferences are noted for concentrations of 25 ppm. of zinc, nickel, manganese, lead, silver, mercury, magnesium, calcium, cadmium, cerium, arsenic, iron, copper, beryllium, chromium, molybdenum, and strontium.

In arriving at the interferences where colored solution was added, a blank was deducted exactly as in the analytical procedure. An error of less than 2 per cent was called none. This conclusion was arrived at in view of the fact that small differences are experimental, and also that the variations in the constituents of aluminum other than copper are of a very small degree. If one considers that 5 ppm. is equivalent to five per cent of that element in the alloy, and that percentage causes an error of only 2 per cent or less, the amount of variation in the alloy will be practically negligible. Copper has no effect at all on the molybdate color after its own blue color is deducted.

Procedure for Analysis:

Dissolve from 50 to 200 mg. of the sample, depending upon the concentration of silicon in the alloy (see Fig. 3), in 18 g. of NaOH solution (20 per cent). This solution shall be prepared by dissolving the pellets in a nickel container. Tare the above-described centrifuge shield containing the drillings on a scale and add the NaOH solution by means of a copper pipette. Cover with a small copper cover and heat over a microburner. Allow the reaction to go to completion in absence of flame and wash down with a very small jet of water. Boil for 10 min. and again wash down the side and the cover with water.

Pour into a 250-ml. beaker containing 25 ml. of HNO_3 (1:5) and 5 ml. of H_2SO_4 (1:1). Wash the contents of the reaction vessel into beaker with water, and police the sides of vessel with 5 ml. of H_2SO_4 (1:10). Wash well with water, and heat the solution just to boiling to dissolve aluminum salts. Cool to 20 C. and adjust to pH 1.4 by dropping NaOH into the solution with the copper pipette, checking with an accurate pH meter.

Transfer to a 200-ml. volumetric flask and dilute to volume with water which has been adjusted to pH 1.4 with H_2SO_4. Pipette from 25 to 75 ml. into a 100-ml. volumetric flask (see working curves, Fig. 3), and dilute to 75 ml. with 1.4 pH water. Add exactly 5 ml. of ammonium peroxidisulphate (4 per cent) and 5 ml. of ammonium molybdate (10 per cent). Read the density at 400 mμ. It is well to run a blank through on the reagents and deduct this density from the above figure. This blank need of course be run only intermittently. Also, read density of the solution in the 200-ml. volumetric flask and deduct whatever portion of this was used in the test. That is, if 25 ml. were taken and diluted to 100 ml. in the final test, deduct one fourth of the difference between this solution and distilled water. This corrects for any of the colored solutions that may be present. Results are naturally much more effective when a very narrow band of light is used for illumination.

TABLE II.—ANALYSIS OF STANDARD SAMPLES.

Analysis	Sample No. 1	Sample No. 2	Sample No. 3	Sample No. 4
Standard........	0.46	1.88	5.57	12.74 avg.
No. 1...........	0.46	1.88	5.58	12.70
No. 2...........	0.46	1.88	5.59	12.65
No. 3...........	0.46	1.87	5.54	12.74
No. 4...........	0.46	1.89	5.55	12.80
No. 5...........	0.46	1.88	5.57	12.77
No. 6...........	0.46	1.86	5.58	12.75
No. 7...........	0.46	1.88	5.60	12.78
No. 8...........	0.46	1.87	5.61	12.75
No. 9...........	0.46	1.88	5.57	12.76
No. 10..........	0.46	1.88	5.60	12.68

It is well to calibrate with standard aluminum alloys. The same working curve (Fig. 3) is of course used for all alloys. We have found it more practical to divide the working curve into several components, depending upon the amount of the sample taken. Naturally, this is a matter of choice, and, as may be seen from the curve, each sample could be calculated on the basis of only one curve.

Results:

The results shown in Table II were obtained by the above method on standard aluminum alloys. Sample No. 1 is the National Bureau of Standards standard sample No. 85. Samples Nos. 2 and 3 are samples upon which considerable work was done by the Aluminum Research Institute. Sample No. 4 is a sample put out by the British Aluminum Co.

REFERENCES

(1) "Analysis of Aluminum and Its Alloys," British Aluminum Company Ltd., *Publication 399* (1941).

(2) "Chemical Analysis of Aluminum," Aluminum Company of America (1941).

(3) W. H. Hadley, "The Determination of Silicon in Aluminum and Its Alloys I," *Analyst*, Vol. 66, p. 486 (1941).

(4) W. H. Hadley, "The Determination of Silicon In Aluminum and Its Alloys II," *Analyst*, Vol. 67, p. 5–8 (1942).

(5) A. Jolles and Fr. Neurath, "Eine Colorimetrische Methode Zur Bestimmung der Kieselsaure Im Wasser," *Zeitschrift fur Angewandte Chemie*, Vol. 11, p. 315 (1898).

(6) H. W. Knudson, C. Juday, V. W. Meloche, "Silicomolybdate Method for Silica," *Industrial and Engineering Chemistry*, Analytical Edition, Vol. 12, p. 270 (1940).

(7) M. C. Schwartz, "Colorimetric Determination of Silica in Boiler Water," *Industrial and Engineering Chemistry*, Analytical Edition, Vol. 6, p. 364 (1934).

(8) H. W. Swank and M. G. Mellon, "Colorimetric Standards for Silica," *Industrial and Engineering Chemistry*, Analytical Edition, Vol. 6, p. 348 (1934).

(9) W. Stross, "Photometric Determination of Silicon in Aluminum Alloys—Observations on Hadley's Method," *Analyst*, Vol. 69, p. 44–45 (1944).

COLORIMETRIC METHODS FOR THE ANALYSIS OF MAGNESIUM-BASE ALLOYS

ASSEMBLED BY V. A. STENGER[1]

The methods presented in this paper have been compiled from various sources and modified for the analysis of magnesium alloys with the aid of a photoelectric colorimeter (filter photometer) or spectrophotometer. Several workers in the Dow laboratories have helped in adapting the procedures. In presenting these methods, there is no implication that they are the best that might be chosen, nor is any claim for originality made except possibly as concerns the determination of iron and copper with hydrobromic acid. The procedures are merely some which have been found reliable. They have been used in some cases for routine analyses, in others for checking or standardizing results obtained by different techniques, such as the spectrographic, and at times for making studies of segregation or other specialized subjects.

DETERMINATION OF MANGANESE BY THE PERIODATE METHOD

1. Principle of Method.—Manganese is oxidized to permanganate by means of potassium periodate in acid solution, according to the method of Willard and Greathouse.[2]

2. Reagents: (a) Nitric Acid (sp.gr. 1.42).—The concentrated acid should be boiled, if necessary, to expel lower oxides of nitrogen.

(*b*) *Sulfuric Acid (1:4).*

(*c*) *Phosphoric Acid (85 per cent).*

(*d*) *Standard Manganese Solution (1 ml. = 0.05 mg. Mn).*—Dissolve 4.061 g. of pure manganese sulfate crystals ($MnSO_4 \cdot 4H_2O$) in water, add 5 ml. of H_2SO_4 (1:4), and dilute to 1 liter. Dilute 50 ml. of this solution to 1 liter to obtain a solution containing 0.05 mg. of manganese per milliliter.

3. Procedure.—(*a*) Weigh out a sample calculated to contain about 1 mg. of manganese. Place in a 250-ml. beaker, add 25 ml. of water, and dissolve in H_2SO_4 (1:4), using about 25 ml. of acid per gram of sample. When the action ceases, add 25 ml. of HNO_3 (sp.gr. 1.42) and heat to dissolve any dark residue. If the solution is turbid it should be filtered at this point. Add 5 ml. of H_3PO_4 (85 per cent) and a few silicon carbide chips, heat almost to boiling, and carefully introduce 0.5 g. of potassium periodate. Boil for 3 min. and then digest just below the boiling point for 15 min. to allow the color to develop fully. Cool and dilute to 100 ml. in a volumetric flask. Mix well, and transfer a portion of the solution to a fused glass absorption cell with a light path of 1 cm. Read the percentage transmittance in a photoelectric colorimeter, using green light having a wave length of approximately 550 $m\mu$ and adjusting the instrument to read 100 per cent against pure water.

(*b*) Prepare a calibration curve by treating known amounts of standard manganese solution (0 to 2 mg. of manganese) in the same way as the sample. Plot the transmittances on the logarithmic scale of semilogarithmic paper against the concentrations in milligrams of manganese per 100 ml. of solution.

(*c*) From the calibration curve read the number of milligrams of manganese present in 100 ml. of sample solution. This value divided by ten and by the number of grams of sample in 100 ml. of solution gives the percentage of manganese in the sample.

---

[1] Analytical Research Chemist, Main Laboratory, The Dow Chemical Co., Midland, Mich.

[2] H. H. Willard and L. H. Greathouse, "The Colorimetric Determination of Manganese by Oxidation with Periodate," *Journal*, Am. Chemical Soc., Vol. 39, p. 2366 (1917).

EXPLANATORY NOTES

NOTE 1.—On alloys of high manganese content (over 1 per cent) use a sample calculated to contain 10 to 15 mg. of manganese. When the action of H_2SO_4 is complete, add 5 ml. of HNO_3 and warm to dissolve any dark residue. Dilute to 250 ml., and pipette out 25-ml. aliquots into 250-ml. beakers. Then add 25 ml. of HNO_3 (sp.gr. 1.42) and continue with the procedure described in Section 3.

NOTE 2.—The distilled water used for dilution after color development should be free of traces of organic matter or other substances which reduce permanganate. Impure water may be boiled with acids and periodate, as described in the procedure, to oxidize any interfering material.

DETERMINATION OF IRON AND COPPER WITH HYDROBROMIC ACID

1. Principle of Method.—In 48 per cent hydrobromic acid ferric iron forms an amber complex, while cupric copper yields a violet complex. Readings of the percentage transmittance at two different wave lengths provide data from which the concentration of each element may be calculated. Since the spectra overlap, the calculation must include a correction for the effect of each element on the reading for the other. The method is best suited for samples containing from 0.002 to 0.04 per cent of iron and 0.006 to 0.08 per cent of copper.

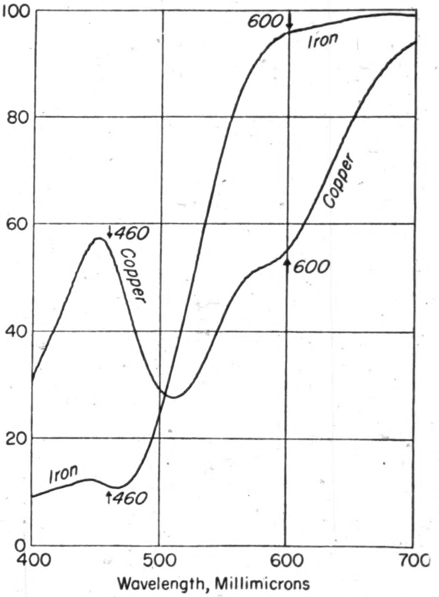


FIG. 1.—Absorption Spectra of Iron and Copper in Hydrobromic Acid.

Iron, 0.10 mg. per 10 ml. Copper, 0.20 mg. per 10 ml. 1.0 cm. cells; H_2O = 100.

2. Reagents: (a) Saturated Solution of Bromine in Water.

(b) Hydrobromic Acid (48 per cent).—Commercial HBr may be used with a blank correction for any iron, copper, or free bromine that it contains, but preferably the acid should be water-white. Distillation in an all-glass apparatus serves to remove bromine, which comes over in the first fractions, and most metals, which remain in the residue. The constant-boiling acid, sp. gr. 1.48, is approximately 48 per cent HBr by weight. Care must be taken to prevent contamination by iron. The acid keeps best in a clear,

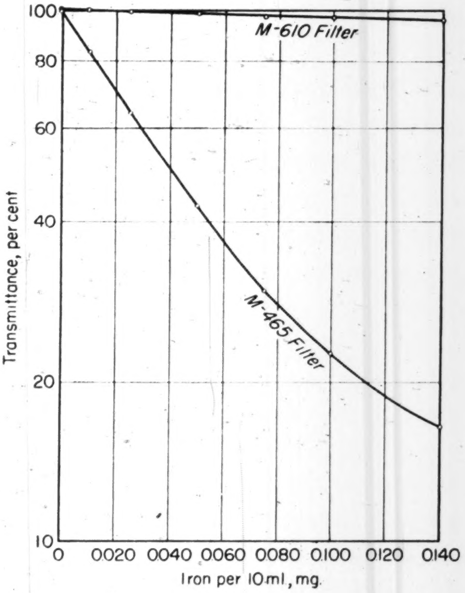


FIG. 2.—Calibration Curves for Iron in Hydrobromic Acid.

Lumetron colorimeter. 1.00-cm. cell.

soft-glass bottle which has previously been given a prolonged soaking in HCl, an old $HClO_4$ bottle is also suitable. The bottle should be painted black on the outside or kept in a dark place.

(*c*) *Standard Iron Solution (1 ml. = 0.01 mg. Fe).*—Dissolve 0.0864 g. of pure ferric ammonium sulfate crystals ($FeNH_4(SO_4)_2 \cdot 12H_2O$) in 100 ml. of water containing 10 ml. of HBr (48 per cent) and dilute to exactly 1 liter with water.

(*d*) *Standard Copper Solution (1 ml. = 0.02 mg. Cu).*—Dissolve 0.0786 g. of pure cupric sulfate crystals ($CuSO_4 \cdot 5H_2O$) in 100 ml. of water containing 10 ml. of HBr (48 per cent) and dilute to exactly 1 liter with water.

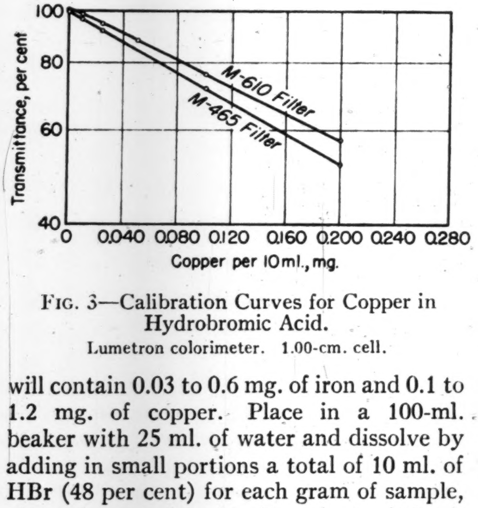


FIG. 3—Calibration Curves for Copper in Hydrobromic Acid.

Lumetron colorimeter. 1.00-cm. cell.

3. *Procedure.*—(*a*) Weigh out a sample of up to 1.5 g. of magnesium alloy, such that it will contain 0.03 to 0.6 mg. of iron and 0.1 to 1.2 mg. of copper. Place in a 100-ml. beaker with 25 ml. of water and dissolve by adding in small portions a total of 10 ml. of HBr (48 per cent) for each gram of sample, plus an excess of 3 ml. Transfer to a 50-ml. volumetric flask, dilute to the mark with water, and mix. Pipette a 10-ml. aliquot into a 50-ml. beaker and add enough bromine water to produce a yellow color; then evaporate nearly to dryness, so that not more than 1 ml. of liquid remains. Add 5 ml. of HBr (48 per cent) and warm if necessary to dissolve the magnesium bromide. If any silica or other insoluble material is present, filter through a small fritted-glass filter crucible (clean and dry) and wash with 1 or 2 ml. of HBr. Transfer the filtrate or the original clear liquid to a 10-ml. glass-stoppered volumetric flask and dilute to the mark with HBr (48 per cent). Mix and place in a fused-glass absorption cell having a 1-cm. light path, for photoelectric measurement.

(*b*) If the colorimeter to be used has an exposed photocell, protect the photocell from acid vapors by inserting next to it a water-filled absorption cell; otherwise proceed in the usual manner. First adjust the instrument to read 100 per cent transmittance against water, with a narrow-band light filter or dial setting selected to give light in the region of 600 mμ. Read the percentage transmittance of the sample at this setting; then adjust the instrument for light in the region of 460 mμ and read the sample again.

(*c*) Prepare calibration curves by treating suitably measured quantities of the standard iron or copper solution (separately) in the same way as the samples, beginning with the point at which bromine water is added. One milliliter of HBr (48 per cent) should be added to each standard before evaporation. Read the percentage transmittance of the prepared standards at each wave length and plot against concentration (milligrams per 10 ml.) on semilogarithmic paper, placing the two iron curves on one sheet and the two copper curves on another.

TABLE I.—DETERMINATION OF IRON AND COPPER IN HYDROBROMIC ACID.

Results on known mixtures.

Milligrams Taken		Milligrams Found	
Iron	Copper	Iron	Copper
0.125	0.025	0.124	0.027
0.050	0.050	0.050	0.050
0.025	0.100	0.024	0.100
0.025	0.0125	0.026	0.014
0.100	0.125	0.092	0.122
0.050[a]	0.050	0.052	0.048

[a] In presence of 0.3 g. Mg^{++}.

(*d*) In order to use the calibration curves, assume as a first approximation that the 460 mμ reading on the sample represents iron and that the 600 mμ reading represents copper. Read the corresponding quantities of iron and copper from the curves, in milligrams per 10 ml. of hydrobromic acid solution. If the two quantities do not differ greatly or if the iron is lower, assume the copper figure to be more nearly correct and use it as a basis for correcting the iron value. If the iron figure is markedly higher, use it to correct the copper value. Make the correction with the aid of the following equation, which holds over the specified concentration range:

$$T_{Fe} \times T_{Cu} = 100 \times T_{obs}$$

where:

T_{Fe} = percentage transmittance in presence of iron alone,

T_{Cu} = percentage transmittance in presence of copper alone, and

T_{obs} = percentage transmittance observed for mixture.

All the symbols refer to measurements at the same wave length.

(*e*) For example, assume that the copper figure is given by the Cu_{600} curve and look up on the Cu_{460} curve the transmittance allowed by this concentration of copper at 460 mμ. Substitute this value as T_{Cu} in the above equation and substitute also the value of T_{obs} as measured for the solution at 460 mμ. Solve for T_{Fe} and read the corresponding concentration of iron from the Fe_{460} curve. This gives a corrected iron concentration. Now use the corrected figure for iron to find T_{Fe} on the Fe_{600} curve. Substitute this and the observed 600-mμ reading in the equation given in Paragraph (*d*), solve for T_{Cu}, and read the corrected copper concentration from the Cu_{600} curve. Calculate the percentage of iron and copper from the corrected concentrations and the following expression:

$$\text{Fe or Cu, per cent} = \frac{\text{milligrams Fe or Cu per 10 ml.} \times 0.1}{\text{grams sample per 10 ml.}}$$

(*f*) In case iron is below 0.02 mg., read copper directly from the 600 mμ curve without correction. Correct the iron concentration for the effect of copper, however.

EXPLANATORY NOTES

NOTE 1.—If the transmittance readings are lower than about 20 per cent at 460 mμ or 50 per cent at 600 mμ, dilute the solution to a larger volume with HBr (48 per cent) and take account of the dilution in the calculation, or repeat using a smaller aliquot of the sample. Do not dilute the acid solution with water, for this causes fading of the color.

NOTE 2.—The procedure as written is most accurate for both constituents when they are present in approximately equal quantities. If one were much higher than the other it would be better to make the reading for the lower constituent on a large sample and to correct it for the other on the basis of what is found in a small sample.

NOTE 3.—Hydrobromic acid solutions of copper develop stronger colors upon standing. The solutions of samples and standards should be read within an hour of the time that the HBr is added (after evaporation).

NOTE 4.—Cobalt, nickel, molybdenum, vanadium, chromium, the platinum metals, and gold would interfere if present, but their colors in HBr are not nearly as sensitive as those of copper and iron.

DETERMINATION OF IRON BY THE DIPYRIDYL METHOD

1. Principle of Method.—Ferrous iron forms a pink complex with α,α'-dipyridyl at a pH of 3 to 4. Control of the pH is necessary, since at lower values the color fades while at higher values there is danger of precipitating aluminum when an alloy is being analyzed. Various combinations of buffers and reducing agents have been suggested, all of which have their particular merits. In this procedure the acidity is controlled by evaporation of excess acid and addition of the required amount. Sodium sulfite serves both as a reducing agent and as a buffer, as originally proposed by Feigl, Krumholz, and Hamburg.[3]

2. Reagents: (*a*) *Hydrochloric Acid (sp. gr. 1.18, iron-free).*

(*b*) *Hydrochloric Acid (1 N).*

(*c*) *Dipyridyl Reagent.*—Dissolve 0.1 g. of α,α'-dipyridyl in 1 ml. of 1 *N* HCl and 9 ml. of water.

(*d*) *Sodium Sulfite Solution.*—Dissolve 10 g. of pure anhydrous Na_2SO_3 in 100 ml. of water. Prepare a fresh solution every three days.

(*e*) *Standard Iron Solution (1 ml. = 0.01 mg. Fe).*—Dissolve 0.0864 g. of pure ferric ammonium sulfate crystals ($FeNH_4(SO_4)_2 \cdot 12H_2O$) in 100 ml. of water containing 5 ml. of HCl (sp. gr. 1.18) and dilute to exactly 1 liter with water.

---

[3] F. Feigl, P. Krumholz, and H. Hamburg, "Über die colorimetrische Bestimmung von Eisen mit a,a'-Dipyridyl," *Zeitschrift anal. Chem.* Vol. 90, p. 199 (1932).

3. Procedure. (*a*) Weigh out a sample of up to 3 g., depending upon the amount of iron expected. Place in a 250-ml. beaker with 50 ml. of water and dissolve by gradually adding HCl (sp. gr. 1.18). Use 7 ml. of HCl per gram of sample, plus an excess of 5 ml., and finally boil the solution after the magnesium has dissolved. Cool, dilute to 100 ml. in a volumetric flask, and mix well. Pipette out an aliquot containing from 0.005 to 0.12 mg. of iron, but preferably not more than 20 mg. of aluminum. Place in a 150-ml. beaker and evaporate just to dryness on a steam bath. (A hot plate may be used if the sample is watched carefully and removed before any magnesium or aluminum chloride decomposes to oxide.)

(*b*) Cool the beaker, add 2 ml. of 1 *N* HCl, and make sure that all the iron and magnesium goes into solution. Add 10 to 15 ml. of water, 2 ml. of dipyridyl reagent, and 1 ml. of Na_2SO_3 solution. Stir, allow to stand for 2 min., add 2 ml. more of Na_2SO_3 solution, and dilute to 50 ml. in a volumetric flask. Mix well and filter if the solution is turbid. A good quality filter paper (low iron) may be used when more than 0.02 mg. of iron is present, but a glass crucible is preferable for smaller amounts. Transfer a convenient quantity of the solution to an absorption cell having a 5 cm. light path, and read in a photoelectric colorimeter using green light of about 520 mμ wave length.

(*c*) Prepare a calibration curve by evaporating measured volumes of the standard iron solution (0 to 0.14 mg. of iron) to dryness on the steam bath and following the procedure described in Paragraph (*b*). Plot the percentage transmittance on the logarithmic scale of semilogarithmic paper against the concentration of iron in the final solution, in mg. per 50 ml.

(*d*) From the calibration curve read the number of milligrams of iron present in 50 ml. of final solution. This figure divided by ten and by the number of grams of sample represented in the aliquot gives the percentage of iron in the sample.

EXPLANATORY NOTES

NOTE 1.—The quantity of dipyridyl specified is sufficient for ordinary alloys containing up to 3 per cent zinc. More might be needed if the zinc content is higher, while less can be used with zinc-free alloys. Zinc forms a colorless complex with dipyridyl.

NOTE 2.—If considerably more copper is present than iron, an interfering green dipyridyl-copper complex may be formed.

DETERMINATION OF SILICON BY THE MOLYBDATE METHOD

1. Principle of Method.—Silicic acid in a true (not colloidal) solution reacts with molybdate to form a yellow molybdisilicic acid. The determination of silica by this method has been studied by many workers and the spectrophotometric principles have been discussed by Swank and Mellon.[4]

2. Reagents: (*a*) *Boric Acid.*—Saturate water with boric acid at room temperature and filter.

(*b*) *Sulfuric Acid* (*1:4*).—Carefully pour 50 ml. of silica-free H_2SO_4 (sp. gr. 1.84) into 200 ml. of water in a Pyrex or Vycor beaker. Prepare freshly as needed.

(*c*) *Ammonium Molybdate Solution.*—Dissolve 40 g. of reagent grade ammonium molybdate tetrahydrate ($(NH_4)_6Mo_7O_{24} \cdot 4H_2O$) in 500 ml. of water.

(*d*) *Standard Sodium Silicate Solution* (*1 ml. = 0.02 mg. Si*).—Dissolve 0.2026 g. of pure sodium silicate crystals ($Na_2SiO_3 \cdot 9H_2O$) in water and dilute to 1 liter.

3. Procedure.—(*a*) Weigh out a sample containing not more than 1 mg. of silicon nor more than 2 g. of magnesium. Place in a 150-ml. beaker with 25 ml. of water and 5 ml. of boric acid solution. From the weight of sample taken calculate the amount of H_2SO_4 (1:4) required to dissolve it, on the basis that 1 g. requires 11.7 ml. of acid. Add this much in small quantities at a time, meanwhile keeping the beaker in a cold water bath to prevent losses of silicon as hydride, and add 1.0 ml. of acid in excess. When the sample is dissolved, introduce about 0.1 g. of potassium persulfate to oxidize ferrous iron or other reducing agents. Allow to stand for 10 min. or longer, dilute to about 60 ml. with water, and filter through retentive low-ash paper, catching the filtrate in a 100-ml. volumetric flask. Rinse the beaker and paper with enough water to make the filtrate about 90 ml. Reserve the filtrate (see Paragraph (*c*)).

---

[4] H. W. Swank and M. G. Mellon, "Colorimetric Standards for Silica," *Industrial and Engineering Chemistry*, Analytical Edition, Vol. 6, p. 348 (1934).

(*b*) Place the filter paper in a clean platinum crucible, burn off at about 500 C., add 0.1 g. of pure anhydrous Na_2CO_3, and fuse at about 850 C. Dissolve the residue in water with enough H_2SO_4 (1:4) to neutralize the Na_2CO_3, plus 1 ml. in excess, and filter into another 100-ml. volumetric flask. Rinse the paper well with water and collect about 90 ml. of filtrate.

(*c*) To each flask add 5.0 ml. of ammonium molybdate solution and dilute with water to 100 ml. Mix well, transfer a sufficient quantity of each solution to an absorption cell having a 5.0-cm. light path, and read the percentage transmittance in blue light having a wave length of approximately 420 mμ with the instrument adjusted to read 100 per cent against pure water.

(*d*) Prepare a calibration curve from known quantities of sodium silicate solution (0 to 1.0 mg. of silicon), each treated with about 40 ml. of water, 1.0 ml. of H_2SO_4 (1:4), 5.0 ml. of ammonium molybdate solution, and enough additional water to make 100 ml. Read the percentage transmittance of each standard in the same way as described in Paragraph (*c*). Plot the transmittance on the logarithmic scale of semilogarithmic paper against the concentration in terms of milligrams of silicon per 100 ml. If the curve does not go through the point of 100 per cent transmittance at zero concentration, draw a new curve parallel to it and passing through this point. The difference may be regarded as a blank correction on the reagents used.

(*e*) From the calibration curve read the number of milligrams of silicon present in 100 ml. of each solution prepared from the sample. Add these together and subtract any blank correction found on the reagents and filter paper (see Explanatory Notes). The result, divided by ten and by the number of grams of sample taken, gives the percentage of silicon in the sample.

EXPLANATORY NOTES

NOTE 1.—A blank should be carried through on all the reagents and the filter paper, except that only 1 ml. of H_2SO_4 (1:4) should be used per 100 ml. of solution, since the color is affected by the acidity.

NOTE 2.—If reducing agents are present, a green color may be produced after the addition of molybdate. This will be restored to yellow upon standing with persulfate, but the samples should not be allowed to stand more than an hour or so between addition of molybdate and reading in the colorimeter.

NOTE 3.—For samples higher in silicon the solutions may be diluted to a larger volume and aliquots analyzed colorimetrically. The final solutions should always contain 1.0 ml. of H_2SO_4 (1:4) and 5.0 ml. of molybdate per 100 ml.

NOTE 4.—Phosphate also gives a yellow color in this reaction. According to rough calculations based on data in the literature, a given weight of phosphorus produces a color a little less than half as intense as that of the same weight of silicon. Since the amount of phosphorus present in a magnesium alloy is generally far below the amount of silicon, no serious interference is to be expected.

DETERMINATION OF LEAD WITH DITHIZONE

1. Principle of Method.—Lead salts react with diphenylthiocarbazone to form a complex which is pink in chloroform solution. The complex is separated from several other metals by extraction of an aqueous ammonium citrate cyanide solution with chloroform and the excess dithizone is removed by extraction of the chloroform layer with ammoniacal cyanide. The procedure is essentially that of Winter, Robinson, Lamb and Miller,[5] but includes some modifications which have been taken from later literature or have been incorporated to make the method more easily applicable to magnesium-base alloys. An excellent review on the determination of lead with dithizone is given by Clifford.[6]

---

[5] O. B. Winter, H. M. Robinson, F. W. Lamb, and E. J. Miller, "Determination of Lead, A Modification of the Fischer-Leopoldi Method," *Industrial and Engineering Chemistry*, Analytical Edition, Vol. 7, p. 265 (1935).

2. *Reagents:* (*a*) *First Extraction Solution.*—To 450 ml. of water, add 30 ml. of a 5 per cent KCN solution, 15 ml. of a 5 per cent ammonium citrate solution (prepared from citric acid and NH_4OH), and 5 ml. of NH_4OH (sp. gr. 0.90).

(*b*) *Second Extraction Solution.*—To 500 ml. of water add 10 ml. of a 5 per cent KCN solution and 5 ml. of NH_4OH.

(*c*) *Dithizone Solution.*—Dissolve 2.5 mg. of diphenylthiocarbazone in 100 ml. of chloroform.

(*d*) *Chloroform* (*lead-free*).—C.P., U.S.P., or technical grade chloroform (stabilized with 0.5 per cent alcohol) is usually satisfactory; if not, it may be purified by the method of Bambach and Burkey.[7]

(*e*) *Standard Lead Solution* (*1 ml. = 0.001 mg. Pb*).—Dissolve 0.1342 g. of pure anhydrous $PbCl_2$ in water containing 1 ml. of HCl (sp. gr. 1.18) and dilute to 1 liter with water. Dilute 10 ml. of this solution to 1 liter with water containing 0.5 ml. of HCl (sp. gr. 1.18) to prepare a solution containing 0.001 mg. of lead per ml.

(*f*) *Hydrochloric Acid* (*1:1*).—Prepare by dilution of lead-free HCl (sp. gr. 1.18).

(*g*) *Ammonium Hydroxide* (*1:10*).—Prepare by dilution of lead-free c.p. NH_4OH (sp. gr. 0.90).

3. *Procedure.*—(*a*) Weigh out a sample calculated to contain 0.1 to 0.7 mg. of lead, place in a 250-ml. beaker with 30 ml. of water, and dissolve by adding 20 ml. of HCl (1:1) per gram. When the magnesium has been dissolved, heat to boiling, dilute to about 200 ml. with water, cool, and transfer to a 500-ml. volumetric flask. Dilute to the mark and mix. Pipette a 10-ml. aliquot into a separatory funnel. Pipette a duplicate aliquot into a beaker and titrate roughly with NH_4OH (1:10) until alkaline to methyl red.

(*b*) To the aliquot in the separatory funnel, add 15 ml. of the first extraction solution (Section 2 (*a*)) and as much NH_4OH (1:10) as was found necessary to neutralize the free acid in the duplicate portion above. From a burette add dithizone solution in 1-ml. steps, introducing just enough so that after shaking and allowing the layers to separate, the lower layer has a noticeable purple to green color as contrasted to pink, indicating a slight excess of dithizone. From another burette add enough chloroform to make the total volume of chloroform and dithizone exactly 10 ml. Shake well and allow the layers to separate. Draw off the chloroform layer into a second separatory funnel containing 20 ml. of the second extraction solution (Section 2 (*b*)). Discard the solution remaining in the first funnel. Shake the second funnel, allow the layers to separate, and drain off the chloroform layer into a third funnel, also containing 20 ml. of the second extraction solution. Shake, separate, and draw off into an absorption cell having a 1.0-cm. light path. A small wad of cotton should be placed in the tube of the separatory funnel to remove any cloudiness or drops of water from the chloroform solution. Read the percentage transmittance for green light having a wave length of approximately 520 mμ, against pure water as 100. Carry a blank determination through all the steps, starting with the same quantity of HCl (1:1) and evaporating off most of it before diluting.

(*c*) Prepare a calibration curve by pipetting from 2 to 14 ml. of the standard lead solution (0.002 to 0.014 mg. of lead) into separatory funnels and carrying through the remaining steps of Paragraph (*b*). Plot the percentage transmittance on the logarithmic axis of semilogarithmic paper against the concentration of lead in terms of milligrams per 10 ml. of chloroform. If the curve does not pass through the point of 100 per cent transmittance and zero concentration, draw a parallel curve through this point and regard the difference as a blank on the reagents.

(*d*) From the calibration curve read the number of milligrams of lead in the 10 ml. of chloroform from extraction of the sample. Subtract from this the quantity of lead found in a blank determination. The result, divided by ten and by the number of grams of sample represented in the aliquot taken, gives the percentage of lead in the sample.

---

[6] P. A. Clifford, "Report on Lead, Dithizone Method and Its Interferences," *Journal*, Assn. Official Agricultural Chemists, Vol. 26, p. 26 (1943).

[7] K. Bambach and R. E. Burkey, "Microdetermination of Lead by Dithizone," *Industrial and Engineering Chemistry*, Analytical Edition, Vol. 14, p. 904 (1942).

EXPLANATORY NOTES

NOTE 1.—Bismuth, thallium, and stannous tin would interfere, but are not likely to be present in magnesium alloys. Bismuth can be compensated for if one makes another reading at 420 to 450 mμ (see the paper by Clifford[6]). Tin may be oxidized to the harmless stannic form by boiling the HCl solution with 1 ml. of HNO_3; the other constituents should then be reduced by boiling with a slight excess of hydroxylamine hydrochloride. The blank should receive the same treatment.

NOTE 2.—The blank color may be due not only to lead but to oxidation products of the dithizone. On this account a blank should be carried through with each series of samples.

NOTE 3.—All glassware to be used in lead determinations should be cleaned thoroughly with HNO_3 and rinsed well.

COLORIMETRIC METHODS FOR THE ANALYSIS OF COPPER-BASE ALLOYS AND REFINED LEAD

ASSEMBLED BY C. ZISCHKAU[1]

The methods presented in this paper have been assembled from various sources and represent procedures that have been found suitable by the submitters for the colorimetric determination of certain elements in copper-base alloys and refined lead.

THE COLORIMETRIC DETERMINATION OF PHOSPHORUS IN PHOSPHORIZED COPPER AND BRASS

(Range, 0.001 to 0.05 per cent Phosphorus)

SUBMITTED BY R. P. NEVERS OF THE AMERICAN BRASS CO., WATERBURY, CONN.

1. Reagents: (*a*) *Sodium Dibasic Phosphate* (*Standard Phosphorus*) *Solution* (*1 ml. = 0.00005 g. P*).—Dissolve 0.2289 g. of highest purity anhydrous sodium dibasic phosphate (Na_2HPO_4) in about 200 ml. of water. Add 100 ml. of HNO_3 (1:5) and dilute to 1 liter with distilled water at 20 C.

(*b*) *Potassium Permanganate Solution* (*1 per cent*).—Dissolve 10 g. of c.p. $KMnO_4$ in 1 liter of distilled water.

(*c*) *Hydrogen Peroxide* (*3 per cent*).—Dilute 50 ml. of H_2O_2 (30 per cent) to 500 ml. with distilled water. Store in a dark bottle in a cool place. The H_2O_2 (30 per cent) should be low in phosphate (maximum, 0.005 per cent PO_4) and free of organic preservatives.[2]

(*d*) *Ammonium Vanadate Solution* (*0.02 N*).—Dissolve 2.345 g. of c.p. ammonium metavanadate (NH_4VO_3) in 500 ml. of hot water. When solution is complete, add 20 ml. of HNO_3 (1:1) and dilute to 1 liter.

(*e*) *Ammonium Molybdate Solution* (*10 per cent*).—Dissolve 100 g. of c.p. ammonium molybdate crystals ($(NH_4)_6Mo_7O_{24} \cdot 4H_2O$) in 600 ml. of hot water. Let stand on the steam bath and stir frequently until solution is complete. Dilute to 1 liter.

2. Preparation of Calibration Curve.—(*a*) Weigh twelve samples of 1.0000 to 1.0050 g. of pure electrolytic copper into 200-ml. beakers. To each sample add 10 ml. of HNO_3 (2:3). Cover and let stand on the steam bath until solution is complete. Reserve two of the samples for "blanks." To the remaining samples add from a 10-ml. microburette the following amounts of standard phosphorus solution:

Milliliters of Solution	Value in Milligrams of Phosphorus	Equivalent Percentage of Phosphorus in Sample
1.0	0.05	0.005
2.0	0.10	0.010
3.0	0.15	0.015
4.0	0.20	0.020
5.0	0.25	0.025
6.0	0.30	0.030
7.0	0.35	0.035
8.0	0.40	0.040
9.0	0.45	0.045
10.0	0.50	0.050

(*b*) Boil covered solutions, including blanks, gently for about 1 min., or until oxides of nitrogen have been expelled. Avoid hard or prolonged boiling, since the loss of HNO_3 will affect the intensity of the color later developed.

---

[1] Advisory Chemist, Analytical Methods, American Smelting and Refining Co., Central Research Dept., Barber, N. J.

[2] Merck Superoxol is satisfactory.

(*c*) Treat each sample as follows: Add 2 ml. of $KMnO_4$ from a burette while the sample is still hot and set on the steam bath for 1 or 2 min. Add 1 ml. of H_2O_2 from a pipette and swirl the sample until the $KMnO_4$ is reduced. Add 2 ml. of ammonium vanadate solution from a burette, while swirling, and boil the sample gently 1 or 2 min., or until the color is a clear blue. Cool to room temperature (25 to 30 C.) in a water bath. Transfer to a 50-ml. volumetric flask and add 2 ml. of the ammonium molybdate solution from a burette. Dilute to the mark with water and mix thoroughly. Let stand 10 min. with occasional shaking and read in a colorimeter, using a blue filter having a maximum transmission at 4250 Å. Longer standing does no harm.

(*d*) From the colorimeter readings (logarithmic scale) plot a curve with percentage of phosphorus on the vertical axis and colorimeter readings on the horizontal axis. A smooth curve approaching a straight line should be obtained. It is convenient for routine work to prepare a chart from this curve directly relating colorimeter readings to percentage of phosphorus.

3. Procedure for Phosphorized Copper.—Weigh 1.0000 to 1.0050 g. of the sample of well-mixed drillings into a 200-ml. beaker. Dissolve and treat the solution exactly as described in the preparation of the calibration curve. Obtain the percentage of phosphorus from the colorimeter reading by reference to the calibration curve or chart.

4. Procedure for Brass.—(*a*) Weigh a sample containing 1.0000 to 1.0050 g. of *copper* into a 200-ml. beaker. Calculate the proper sample weight for any alloy as follows:

$$\text{Sample wt. to contain 1 g. of copper} = \frac{100}{\text{percentage of copper in alloy}}$$

Proper sample weights for the alloys most commonly analyzed for phosphorus are as follows:

No. 14 alloy (90 per cent Cu)	1.1100 to 1.1150 g.
No. 42 alloy (70 per cent Cu)	1.4300 to 1.4350 g.

(*b*) In dissolving brass samples, 0.7 ml. excess of HNO_3 (2:3) should be added for every 100 mg. of sample over 1 g. Proper amounts of HNO_3 (2:3) for dissolving the alloys mentioned above are as follows:

No. 14 alloy	11 ml.
No. 42 alloy	13 ml.

(*c*) After solution of the sample, the analysis is carried out in exactly the same way as that of phosphorized copper. Calculate the percentage of phosphorus as follows:

$$\text{Percentage of phosphorus in brass sample} = \frac{\text{percentage of phosphorus from calibration chart}}{\text{wt. in grams of sample}}$$

Since the amount of phosphorus in brass usually is below 0.01 per cent, it is well to redetermine carefully this portion of the calibration curve, paying especial attention to the blank reading, or zero point, and plotting the curve on an enlarged scale.

THE COLORIMETRIC DETERMINATION OF PHOSPHORUS IN BRONZES[3]

(Range, 0.05 to 0.50 per cent Phosphorus)

SUBMITTED BY R. P. NEVERS OF THE AMERICAN BRASS CO., WATERBURY, CONN.

1. Reagents: (*a*) *Sodium Dibasic Phosphate* (*Standard Phosphorus*) *Solution* (*1 ml. = 0.0005 g. P*).—Dissolve 2.2894 g. of highest purity anhydrous sodium dibasic phosphate (Na_2HPO_4) in about 200 ml. of water. Add 100 ml. of HNO_3 (1:5), and dilute to 1 liter with distilled water at 20 C.

(*b*) *Ammonium Vanadate Solution* (*0.02 N*) *and Ammonium Molybdate Solution* (*10 per cent*).—See Section 1 (*d*) and (*e*) under "The Colorimetric Determination of Phosphorus in Phosphorized Copper and Brass."

---

[3] For additional information see the paper by W. M. Murray, Jr., and S. E. Q. Ashley, "Determination of Manganese, Nickel and Phosphorus in Iron and Steel," *Industrial and Engineering Chemistry*, Analytical Edition, Vol. 10, No. 1, pp. 1-5 (1938).

2. Preparation of Calibration Curve.—(*a*) Weigh 10 samples of 0.5000 to 0.5050 g. of pure electrolytic copper into 200-ml. beakers. To each sample add 3 ml. of HCl (sp. gr. 1.18) and 30 ml. of HNO_3 (1:2). Cover and let stand on the steam bath until solution is complete. From a 10-ml. microburette, add the following amounts of standard phosphorus solution:

Milliliters of Solution	Value in Milligrams of Phosphorus
0.5	0.25
1.0	0.50
1.5	0.75
2.0	1.00
2.5	1.25
3.0	1.50
3.5	1.75
4.0	2.00
4.5	2.25
5.0	2.50

(*b*) Boil covered solutions gently for *exactly* 5 min. No odor of free chlorine should be perceptible at this point. Avoid prolonged boiling, as HCl will be lost and tin precipitated. Add 10 ml. of the ammonium vanadate solution from a burette to each sample while still hot. Transfer to a 250-ml. volumetric flask, cool to room temperature (25 to 30 C.) in a water bath, and add 10 ml. of the ammonium molybdate solution from a burette. Dilute to the mark with water and mix thoroughly. Let stand 20 min. with occasional mixing and read in a colorimeter, using a blue filter having a maximum transmission at 4250 Å. Longer standing does no harm.

(*c*) From the colorimeter readings plot a curve with milligrams phosphorus on the vertical axis and colorimeter readings on the horizontal axis. A smooth curve approaching a straight line should be obtained. It is convenient for routine work to prepare a chart from this curve directly relating colorimeter readings to the phosphorus equivalents in milligrams.

3. Procedure.—Weigh 0.5400 to 0.5450 g. of the sample of well-mixed drillings into a 200-ml. beaker. Dissolve and treat the solution exactly as described in the preparation of the calibration curve. Obtain the phosphorus value from the colorimeter reading by reference to the calibration curve or chart. Calculate the percentage of phosphorus as follows:

$$\text{Phosphorus, per cent} = \frac{\text{mg. of phosphorus}}{\text{wt. of sample}} \times \frac{1}{10}$$

NOTE.—The theoretical sample weight should be such that the sample will contain exactly 0.5 g. of copper. A sample weight of 0.5400 to 5450 g. approaches this condition closely enough for most phosphor bronzes analyzed in this laboratory.

THE DIRECT PHOTOMETRIC DETERMINATION OF SILICON IN COPPER-BASE ALLOYS[4]

(For Alloys Containing up to 0.20 per cent Silicon)

SUBMITTED BY O. P. CASE of THE AMERICAN BRASS CO., WATERBURY, CONN.

1. Reagents: (*a*) *Nitric Acid* (*1:2*).—Dilute one volume of reagent grade HNO_3 with two volumes of water.

(*b*) *Hydrofluoric Acid* (*48 per cent*).—Use reagent grade HF (48 per cent). Even the best grades of HF appear to contain a small amount of H_2SiF_6.

(*c*) *Boric Acid* (*saturated solution*).—Dissolve 65 g. of reagent grade boric acid crystals (H_3BO_3) in 1 liter of hot water. Cool to room temperature.

(*d*) *Ammonium Molybdate Solution* (*10 per cent*).—Dissolve 100 g. of reagent grade ammonium molybdate crystals ($(NH_4)_6Mo_7O_{24} \cdot 4H_2O$) in hot water. Cool and dilute to 1 liter. Filter if the solution is not clear.

(*e*) *Citric Acid Solution* (*10 per cent*).—Dissolve 100 g. of reagent grade citric acid crystals ($C_6H_8O_7 \cdot H_2O$) in water and dilute to 1 liter.

---

[4] For a detailed description of this method, see the original paper by O. P. Case. For additional information see the following references:

H. W. Knudson, C. Juday, V. W. Meloche, *Industrial and Engineering Chemistry*, Analytical Edition, Vol. 12, p. 270 (1940).

P. Z. Krumhols, *Zeitschrift Anorg. Allgem. Chem.*, Vol. 212, p. 91 (1933).

M. C. Schwartz, *Industrial and Engineering Chemistry*, Analytical Edition, Vol. 6, p. 364 (1934).

M. C. Schwartz and L. W. Morris, *Industrial and Engineering Chemistry*, Analytical Edition, Vol. 15, p. 20 (1943).

(*f*) *Standard Silicate Solution* (*1 ml. = 0.0001 g. Si*).—Fuse 0.2141 g. of pure anhydrous silica (SiO_2) with 2 g. of Na_2CO_3 in a platinum crucible. Heat at slightly above fusion temperature for about 15 min., cool, and dissolve the melt in warm water, using a platinum dish for a container. Cool the solution and transfer to a 1-liter volumetric flask. Dilute to the mark and mix thoroughly. Store the solution in a wax or hard rubber bottle.

2. *Preparation of Calibration Curve.*—Weigh portions of high purity copper equivalent to the amount of copper (plus or minus 25 mg.) present in a 1-g. sample of the alloy under test. Very fine pieces of metal (finer than 35-mesh) and light, feathery drillings should be avoided as they react too vigorously with the dissolving acid. Transfer to platinum crucibles of at least 20-ml. capacity, fitted with covers. Somewhat larger crucibles are preferable if available. To each portion of metal add 10 drops of HF (0.3 to 0.4 ml.), followed by an amount of HNO_3 (1:2) equivalent to 0.6 ml. for each 100 mg. of metal plus 6 ml. in excess. Cover the crucibles and let stand until the vigorous reaction has subsided, when they may be placed on the steam plate to complete solution. With the aid of a long-stem hard rubber or plastic funnel, transfer the contents of the crucibles to 200-ml. volumetric flasks containing 25 ml. of boric acid solution. Rinse the crucibles and sides of the flask and immediately swirl the flasks to mix the solutions thoroughly. From a microburette add amounts of standard silicate solution to cover the desired range of silicon in steps of 0.2 mg. Cool the solutions to room temperature and add 10 ml. of ammonium molybdate solution to each. Dilute to the mark and mix thoroughly. Let the solutions stand for 15 min. and read the transmission or relative density of the color with a photometer at approximately 410 mμ. Plot the photometer readings against milligrams of silicon, or percentage of silicon.

3. *Procedure for Samples Containing No Phosphorus.*—Treat a 1 to 1.0050-g. sample of the alloy under test exactly as described in Section 2, omitting the addition of the standard silicate solution. Read the percentage of silicon directly from the calibration curve.

4. *Procedure for Samples Containing Phosphorus.*—The procedure for the determination of silicon in the presence of phosphorus is as follows: Treat the sample as described in Section 2 until the ammonium molybdate has been added, then dilute the sample solution to 175 ml. and let stand for 10 min. Add 5 ml. of citric acid (10 per cent), dilute to the mark, mix thoroughly, and read the color value at once.

NOTE.—Under the above conditions the phosphorus complex is bleached almost at once, while the silicon complex is not significantly affected for several minutes. Five milliliters of citric acid (10 per cent) is sufficient to destroy the color developed by 2.5 mg. of phosphorus.

THE COLORIMETRIC DETERMINATION OF MANGANESE IN COPPER ALLOYS[5]

SUBMITTED BY F. M. BARRY OF THE SCOVILL MANUFACTURING CO., WATERBURY, CONN.

1. *Reagents:* (*a*) *Bright-Larabee Acid Mixture.*—Mix 100 ml. of H_2SO_4 (sp. gr. 1.84), 125 ml. of H_3PO_4 (85 per cent), 250 ml. of HNO_3 (sp. gr. 1.20), and 525 ml. of water.

(*b*) *Silver Nitrate Solution* (*0.8 per cent*).—Dissolve 0.8 per cent by weight of $AgNO_3$ in water.

(*c*) *Ammonium Persulfate Solution* (*25 per cent*).—Dissolve 25 per cent by weight of ammonium persulphate ($(NH_4)_2S_2O_8$) in water.

2. *Preparation of Standards.*—Prepare standards by adding known amounts of 0.05 *N* $KMnO_4$ to brasses or other copper alloys (whose manganese content has been

---

[5] For additional information see the paper by K. W. Silverthorne and J. Alfred Curtis on "Colorimetry in Metallurgical Analysis," *Metals and Alloys*, Vol. 15, No. 2, February, 1942.

determined) and following the procedure outlined in Section 3. As an example, standards may be prepared such that each contains 1.000 g. of manganese-free brass plus the following amounts of 0.05 *N* $KMnO_4$: 0, 0.5, 1.0, 1.5, 2.0, and 3.0 ml., respectively.

3. *Procedure for Standards and Samples.*—(*a*) Weigh a 1.0000-g. sample and transfer to a 500-ml. Erlenmeyer flask. Add 30 ml. of Bright-Larabee acid mixture (Section 1 (*a*)). Heat until solution is complete and acid fumes are driven off. Add 100 ml. of hot water and 10 ml. of $AgNO_3$ (0.8 per cent) and bring to a boil. Add 10 ml. of $(NH_4)_2\ S_2O_8$ (25 per cent) and boil exactly 1 min.

(*b*) Cool and dilute to exactly 200 ml. Take the photometer reading, using a No. 525 filter.

THE COLORIMETRIC DETERMINATION OF IRON IN COPPER ALLOYS (THIOCYANATE METHOD)[6]

SUBMITTED BY THE SCOVILL MANUFACTURING CO., WATERBURY, CONN.

1. *Reagents:* (*a*) *Standard Iron Solution.*—Dissolve 0.5000 g. of pure iron wire in 10 ml. of HNO_3 (1:2) and dilute to 1 liter. Determine the iron content accurately.

(*b*) *Electrolysis Mixture.*—Mix 500 ml. of H_2SO_4 (sp. gr. 1.84), 300 ml. of HNO_3 (sp. gr. 1.42), and 1700 ml. of water.

(*c*) *Hydrogen Peroxide* (3 per cent).

(*d*) *Hydrochloric Acid* (*sp. gr. 1.19*).

(*e*) *Ammonium Thiocyanate Solution* (*10 per cent*).—Dissolve 10 per cent by weight of ammonium thiocyanate in distilled water.

2. *Preparation of Standards.*—Prepare standards by adding definite amounts of an iron solution of known iron content to brasses or other copper alloys (whose iron content has been determined) and following the procedure outlined in Section 3.

3. *Procedure for Standards and Samples.*—(*a*) Weigh a 1.0000-g. sample and transfer to a 200-ml. electrolysis beaker.

(*b*) Dissolve and electrolyze as outlined in the A.S.T.M. Tentative Methods of Chemical Analysis of Brasses (E 36 – 42 T),[7] following either the "Determination of Copper by the Electrolytic Method" or the "Determination of Copper and Lead Simultaneously by the Electrolytic Method". Reserve electrolyte and washings.

(*c*) Transfer the electrolyte to a 1-liter volumetric flask and dilute to the mark with distilled water. Pipette 50 ml. of solution into a 200-ml. volumetric flask.

(*d*) Add in succession to the 200-ml. flask, with stirring, 1.0 ml. of HCl (sp. gr. 1.19), 1.0 ml. of H_2O_2 (3 per cent) and 25 ml. of ammonium thiocyanate (10 per cent). Dilute to the mark and mix thoroughly. Take the photometer reading, using a No. 525 filter.

---

[6] For additional information see the following references:

Charles A. Peters, Majel M. MacMasters, and Chester L. French, "Hydrogen Peroxide in Colorimetric Determination of Iron by Thiocyanate," *Industrial and Engineering Chemistry*, Analytical Edition, Vol. 11, No. 9, p. 502 (1939).

J. T. Woods and M. G. Mellon, "Thiocyanate Method for Iron," *Industrial and Engineering Chemistry*, Analytical Edition, Vol. 13, No. 8, p. 551 (1941).

[7] A.S.T.M. Methods of Chemical Analysis of Metals (1943), p. 168.

THE COLORIMETRIC DETERMINATION OF NICKEL IN COPPER ALLOYS

SUBMITTED BY F. M. BARRY OF THE SCOVILL MANUFACTURING CO., WATERBURY, CONN.

1. *Reagents:* (*a*) *Standard Nickel Solution.*—Dissolve 0.5000 g. of high purity nickel in 10 ml. of HNO_3 (1:1) and dilute to 1 liter with distilled water.

(*b*) *Electrolysis Mixture.*—Mix 500 ml. of H_2SO_4 (sp. gr. 1.84), 300 ml. of HNO_3 (sp. gr. 1.42), and 1700 ml. of water.

(*c*) *Citric Acid Solution* (*10 per cent*).—Dissolve 100 g. of citric acid crystals in 1 liter of distilled water.

(*d*) *Bromine Water.*—Saturate distilled water with bromine, add a slight excess, and keep in a glass-stoppered bottle.

(*e*) ***Ammonium Hydroxide*** (*1:1*).—Mix 500 ml. of NH_4OH (sp. gr. 0.90) and 500 ml. of distilled water.

(*f*) *Dimethylglyoxime Solution.*—Dissolve 10 g. of the c. p. salt in 1000 ml. of 95 per cent ethyl alcohol and filter before using.

2. Preparation of Standards.—Standards may be prepared by adding definite amounts of a carefully standardized nickel nitrate solution to brasses or other copper alloys of known nickel content and following the procedure outlined in Section 3.

3. Procedure for Standards and Samples.— (*a*) Weigh a 1.0000-g. sample and transfer to a 200-ml. electrolysis beaker.

(*b*) Dissolve and electrolyze as outlined in the A.S.T.M. Tentative Methods of Chemical Analysis of Brasses (E 36–42 T),[7] following either the "Determination of Copper by the Electrolytic Method" or the "Determination of Copper and Lead Simultaneously by the Electrolytic Method." Reserve the electrolyte and washings.

(*c*) Transfer the electrolyte to a 1-liter volumetric flask and dilute to the mark with distilled water. Pipette 50 ml. of the solution into a 200-ml. volumetric flask.

(*d*) Add the following reagents to the 50-ml. sample in the flask in the order given and with thorough mixing after each addition: 10 ml. of citric acid solution (10 per cent), 5 ml. of saturated bromine water, 10 ml. of NH_4OH (1:1), and 3 ml. of a 1 per cent solution of dimethylglyoxime in alcohol.[3]

(*e*) Dilute the contents to the mark with distilled water and mix thoroughly. Take the photometer reading within 10 min. after the addition of the reagents, using a No. 525 filter.

THE PHOTOMETRIC DETERMINATION OF BISMUTH IN REFINED LEAD WITH THIOUREA

SUBMITTED BY C. ZISCHKAU OF THE AMERICAN SMELTING AND REFINING CO., CENTRAL RESEARCH DEPT., BARBER, N. J.

1. Reagents: (*a*) *Nitric Acid* (*1:9*).—Mix 100 ml. of HNO_3 (sp. gr. 1.42) with 900 ml. of water.

(*b*) *Thiourea Solution* (*5 per cent*).—Dissolve 5 g. of thiourea in water, dilute to 100 ml., and filter. Make a fresh solution daily.

2. Procedure.—(*a*) The lead should be rolled into a thin strip to facilitate solution. Weigh 1.000 g. of lead into a small beaker or a 50-ml. volumetric flask and add 15 ml. of HNO_3 (1:9). Heat to dissolve the sample, boil off the brown fumes, and cool to room temperature. If the sample was dissolved in a beaker, transfer the solution to a 50-ml. volumetric flask with about 20 ml. of water. If the sample was dissolved in a 50-ml. volumetric flask, dilute with 20 ml. of water. Add 10 ml. of thiourea[8] solution and dilute to the mark with water. Mix and transfer to a cell for measurement, using a No. 420 Corning glass filter.

(*b*) The amount of bismuth present will determine the weight of sample to be taken. For 0.01 to 0.10 per cent of bismuth take a 1-g. sample. For samples containing less than 0.01 per cent of bismuth take a 2-g. sample, in which case 25 ml. of HNO_3 (1:9) would be used to dissolve the sample. A blank, for the initial setting of the instrument, is made by dissolving the same weight of bismuth-free lead and carrying it through the same procedure as for the regular determination (Paragraph (*a*)).

3. Calibration Curve.—To definite weights of bismuth-free lead (1 or 2 g.) add known amounts of bismuth as bismuth nitrate, and follow the same procedure as described in Section 2. A curve can be plotted from percentage transmission, or density, against concentration.

---

[8] C. Mahr, *Zeitschrift Anal. Chem.*, Vol. 94, p. 161 (1933); Vol. 97, p. 96 (1934).

THE PHOTOMETRIC DETERMINATION OF BISMUTH IN REFINED LEAD AS IODIDE

SUBMITTED BY C. ZISCHKAU OF THE AMERICAN SMELTING AND REFINING CO.,
CENTRAL RESEARCH DEPT., BARBER, N. J.

1. Reagents: (*a*) *Sulfuric Acid (sp. gr. 1.84).*

(*b*) *Hydrochloric Acid (1:1).*—Mix equal volumes of HCl (sp. gr. 1.19) and water.

(*c*) *Potassium Iodide Solution.*—Dissolve 20 g. of KI and 0.75 g. of anhydrous Na_2SO_3 in water and dilute to 100 ml.

2. Procedure.—(*a*) The lead should be rolled into a thin sheet to facilitate solution. For lead analyzing from 0.003 to 0.05 per cent of bismuth, weigh 4.00 g. into a 250-ml. beaker. For higher bismuth, approximately 0.10 per cent, weigh 2.00 g. Add 10 to 12 ml. of H_2SO_4 (sp. gr. 1.84), cover the beaker, and heat over a burner, rotating the beaker, until the lead has been converted to sulfate. Place on a hot plate, remove the cover, and fume until practically all the H_2SO_4 has been expelled. Remove from the heat, cool, and add 20 ml. of HCl (1:1). Cover the beaker and boil for several minutes; then place on cooler part of the hot plate to prevent bumping (about 5 min. heating is sufficient). Remove from the hot plate, cool to room temperature, and add 25 ml. of ethyl alcohol. Transfer to a 50-ml. volumetric flask, dilute to 51 ml. for a 4-g. sample, and cool in ice-water. Filter or centrifuge, and transfer 25 ml. of the solution for analysis to a 100-ml. volumetric flask. Dilute to about 90 ml. with water, add 5 ml. of KI solution, and dilute to the mark with water. Mix and transfer to a cell for measurement, using a No. 420 Corning glass filter.

(*b*) A blank, for the initial setting of the instrument, is made by dissolving the same weight of bismuth-free lead and following the procedure described in Paragraph (*a*).

3. Calibration Curve.—Add known amounts of bismuth to definite weights of bismuth-free lead and follow the regular procedure (Section 2). A curve can be plotted from percentage transmission, or density, against concentration

COLORIMETRIC METHODS FOR THE ANALYSIS OF FERROUS ALLOYS

Assembled by Arba Thomas[1]

The methods presented in this paper have been assembled from various sources and represent procedures that have been found suitable by the submitters, for the colorimetric determination of certain elements in ferrous alloys.

COLORIMETRIC DETERMINATION OF COPPER IN IRON AND STEEL BY THE DIETHYL-DITHIOCARBAMATE METHOD

Submitted by Arba Thomas, The American Rolling Mill Co.

1. Principle of Method.—The procedure described below is especially designed for the rapid routine determination of copper in steels where the nickel content is below 0.25 per cent (Note 1). In this procedure the color measurements are made with a Klett-Summerson photoelectric colorimeter, using Klett filter No. 47 (transmission limits 445 to 505 mμ).

2. Reagents: (a) Ammonium Persulfate (4 per cent).—Dissolve 4 g. of reagent grade ammonium persulfate ($(NH_4)_2S_2O_8$) in 100 ml. of distilled water. This solution should be made up fresh daily.

(b) Sodium Diethyl Dithiocarbamate (0.15 per cent).—Dissolve 1.5 g. of sodium diethyl dithiocarbamate in 1 liter of distilled water. Store in a brown bottle, and prepare fresh each month.

3. Procedure.—(*a*) Dissolve 0.1 g. (Note 2) of millings or drillings in a 125-ml. Erlenmeyer flask with 10 ml. of HNO_3 (1:2) (Note 3). Add 15 ml. of ammonium persulfate (4 per cent) and boil for 1 min. Remove from the hot plate, cool, and add 10 ml. of citric acid solution (35 per cent) and 10 ml. of NH_4OH (sp. gr. 0.90). Cool to room temperature and add approximately 1 ml. of NH_4OH (sp. gr. 0.90) and 10 ml. of sodium diethyl dithiocarbamate. Mix, and allow to stand for 15 to 40 sec. Transfer to a 125-ml., pear-shape separatory funnel, add 50 ml. of butyl acetate, and mix thoroughly by shaking. Place the funnel in an upright position, and allow the layers to separate. Carefully drain and discard the lower acid layer; then drain the butyl acetate layer containing the extracted colored copper compound into a dry 50 ml. volumetric flask. Dilute to 50 ml. with butyl acetate and mix thoroughly by shaking.

(*b*) Rinse out the colorimeter absorption tube with a few millimeters of the colored butyl acetate solution, discard, and then add at least 5 ml. of the colored solution to the absorption tube. Carefully wipe the tube to remove stains, place in the photoelectric colorimeter (Note 4), and determine the dial reading (Note 5). Correct the dial reading for a blank (Note 6), and determine the percentage of copper by reference to a conversion chart or a calibration curve (Note 7) previously prepared.

---

[1] Chief Chemist, Research Laboratories, The American Rolling Mill Co., Middletown, Ohio.

EXPLANATORY NOTES

NOTE 1.—Cobalt above 0.10 per cent also interferes. Nickel and cobalt form compounds with diethyl dithiocarbamate and are extracted with butyl acetate. However, small amounts do not seriously interfere when filter No. 47 is used.

NOTE 2.—An 0.05-g. sample should be used when the copper is over 0.25 per cent.

NOTE 3.—Add 1 ml. of HCl (sp. gr. 1.18) when dissolving high-chromium steels.

NOTE 4.—The zero adjustment of the Klett-Summerson photoelectric colorimeter, with filter No. 47 in place, should be obtained previously by using butyl acetate as the reference solution. In making the zero adjustment, see that filter No. 47 is in place and the absorption tube contains clean butyl acetate. Place the absorption tube in the colorimeter, turn on the light and instrument, and leave it on for a few minutes. Then set the scale dial on zero and adjust the zero adjustment knob, which is to the left of the absorption cell, until the pointer is brought back exactly to the zero line.

NOTE 5.—In determining the dial reading the scale dial is turned until the pointer is brought back exactly to the zero line.

NOTE 6.—A blank should be determined on the reagents alone, and a new blank determined whenever a new lot of reagents is obtained.

NOTE 7.—The calibration curve is not a straight line; therefore a factor cannot be used. The calibration curve must be carefully prepared using standard steels of known copper contents. From the calibration curve a conversion table may be prepared if desired. The curve (Fig. 1) and conversion table (Table I) given in this method are for the Armco Research Klett-Summerson instrument only and are shown for purposes of illustration.

TABLE I.—CONVERSION TABLE FOR COPPER-DIETHYL DITHIOCARBAMATE COLORIMETRIC METHOD.

(0.1-g. Sample Diluted to 50 ml. with Butyl Acetate, Using the Klett-Summerson Colorimeter with Filter No. 47)

Corrected Reading	Copper, per cent	Corrected Reading	Copper, per cent	Corrected Reading	Copper, per cent
10	0.010	78	0.084	146	0.168
12	0.012	80	0.086	148	0.171
14	0.014	82	0.088	150	0.174
16	0.016	84	0.091	152	0.176
18	0.018	86	0.093	154	0.179
20	0.020	88	0.095	156	0.182
22	0.023	90	0.097	158	0.185
24	0.025	92	0.099	160	0.188
26	0.027	94	0.102	162	0.190
28	0.029	96	0.104	164	0.193
30	0.031	98	0.106	166	0.196
32	0.033	100	0.109	168	0.199
34	0.035	102	0.111	170	0.202
36	0.037	104	0.113	172	0.205
38	0.039	106	0.116	174	0.208
40	0.041	108	0.118	176	0.211
42	0.043	110	0.120	178	0.214
44	0.046	112	0.123	180	0.217
46	0.048	114	0.125	182	0.220
48	0.050	116	0.128	184	0.223
50	0.052	118	0.130	186	0.226
52	0.054	120	0.133	188	0.229
54	0.056	122	0.136	190	0.232
56	0.058	124	0.138	192	0.235
58	0.061	126	0.141	194	0.239
60	0.063	128	0.144	196	0.242
62	0.065	130	0.146	198	0.245
64	0.067	132	0.149	200	0.248
66	0.070	134	0.152	202	0.251
68	0.072	136	0.155	204	0.254
70	0.074	138	0.157	206	0.258
72	0.076	140	0.160	208	0.261
74	0.079	142	0.163	....	......
76	0.082	144	0.165	....	......

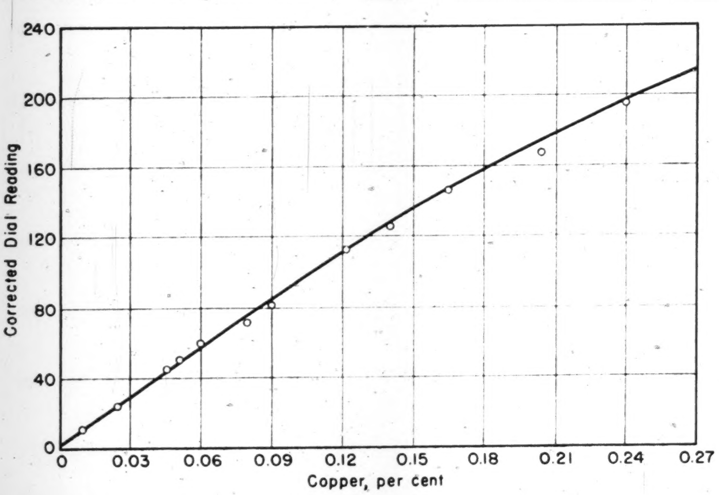


Fig. 1.—Calibration Curve for the Determination of Copper in Iron and Steel by the Diethyl Dithio-Carbamate Method—Research Laboratories' Klett-Summerson Photoelectric Colorimeter Using Klett Filter No. 47.

(0.1-g. sample diluted to 50 ml. with Butyl Acetate.)

COLORIMETRIC DETERMINATION OF TITANIUM IN CHROMIUM-ALLOYED STEELS, USING A KLETT-SUMMERSON PHOTOELECTRIC COLORIMETER WITH FILTER NO. 42

SUBMITTED BY ARBA THOMAS, THE AMERICAN ROLLING MILL CO.

1. *Principle of Method.*—This method is based on the removal of chromium by volatilization as chromyl chloride and the ultimate determination of titanium colorimetrically by measurement of the intensity of color developed by hydrogen peroxide by means of a Klett-Summerson photoelectric colorimeter, using filter No. 42 (transmission limits 400 to 450 mμ). The procedure described below is especially designed for the rapid routine determination of titanium in stainless steels (ferritic and austenitic) and in chromium steels where the vanadium content is below 0.05 per cent, and is most satisfactory when the titanium content is in the range of 0.10 to 0.60 per cent (Note 1). Vanadium interferes, if present in amounts above 0.05 per cent.

2. *Procedure.*—(*a*) Dissolve 0.5 g. of millings or drillings in a 500-ml. wide-mouth Erlenmeyer flask with 15 ml. of HCl (sp. gr. 1.18) and 5 ml. of HNO_3 (sp. gr. 1.42). Add 30 ml. of $HClO_4$ (70 per cent), take to copious fumes, and fume profusely for 5 min., or for 2 to 3 min. after the solution turns to a reddish orange color (Note 2). In one addition add 2 to 3 g. of solid NaCl to volatilize most of the chromium. After the NaCl is dissolved, continue to boil the solution for 1 to 2 min. to expel the HCl (Note 3). Remove the flask from the hot plate, cool slightly, cautiously wash down the sides of the flask with hot water, and dilute to 75 ml. Place the flask on a hot plate and boil for 2 min. to remove free chlorine. Add 1 to 2 ml. of a 6 per cent solution of $NaNO_2$ to reduce any chromium remaining in the solution, and continue boiling until all brown fumes are expelled. Cool the solution to room temperature, filter to remove silicic acid, catching the filtrate in a 100 ml. volumetric flask, wash with cold water, and dilute to the mark.

(*b*) Rinse the colorimeter absorption tube first with distilled water, followed by a portion of the solution. Discard, and then add at least 5 ml. of the solution to the absorption tube (Note 4). Carefully wipe the tube to remove fingerprints or stains, place the tube in the photoelectric colorimeter, and make the zero adjustment (Note 5). Add 1 ml. of H_2O_2 (30 per cent) to the main solution in the volumetric flask to develop the titanium color. Discard the reference solution and add at least 5 ml. of the colored solution to the colorimeter absorption tube, again wipe the tube to remove stains, place in the colorimeter in exactly the same position as before, and determine the dial reading (Note 6). Calculate the percentage of titanium present by multiplying the dial reading by a predetermined factor (Note 7), or find the percentage of titanium present from a conversion graph previously prepared (Note 8).

EXPLANATORY NOTES

NOTE 1.—The titanium value obtained by this method does not include that present as titanium oxide (TiO_2). The amount of titanium oxide present in titanium-bearing steels, such as 18-10 Ti stainless, is generally insignificant, so that for all practical purposes the percentage of titanium found may be reported as total titanium.

NOTE 2.—The chromium must be completely oxidized and the $HClO_4$ fuming profusely for best efficiency in removing the chromium.

NOTE 3.—Do not evaporate below 10 ml., as on subsequent dilution hydrolysis of titanium hydroxide is likely to occur if the acidity is too low.

NOTE 4.—In this procedure the $HClO_4$ solution containing the iron, nickel, titanium, etc., is used as the reference solution before H_2O_2 is added. In this way the dial is a reading measure of the light absorbed by the titanium color only. The absorption cell must be well rinsed at this point if previously used for titanium, as any trace of H_2O_2 left in the tube will partially develop the titanium color.

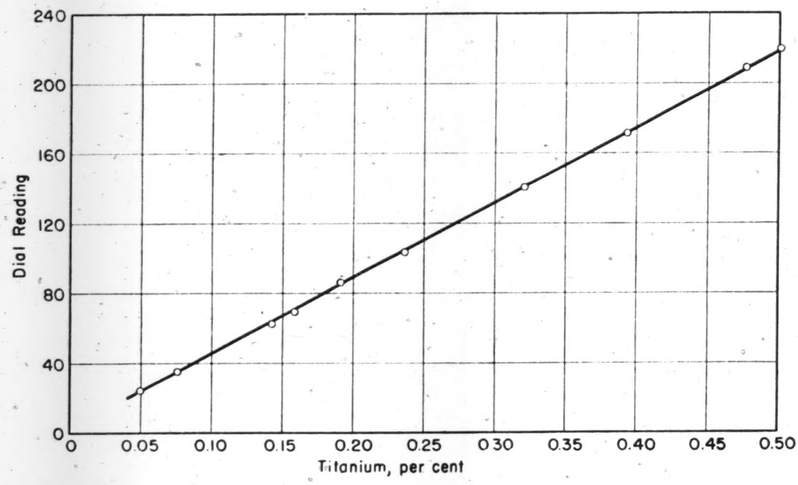


Fig. 2.—Colorimetric Determination of Titanium in Stainless Steel With Klett-Summerson Photoelectric Colorimeter, Using Filter No. 42.
(0.5-g. sample diluted to 100 ml.)

NOTE 5.—In making the zero adjustment, the scale dial is set on zero and the instrument is allowed to reach equilibrium by leaving it on for at least 15 min.; then the zero adjustment knob, which is to the left of the absorption cell, is adjusted until the pointer is brought back exactly to the zero line.

NOTE 6.—In determining the dial reading, the knob is turned until the pointer is brought back exactly to the zero line.

NOTE 7.—When the scale reading is plotted against the percentage of titanium, a straight line is obtained when the percentage of titanium is from 0.10 to 0.60 per cent; therefore, the factor may be determined by using Bureau of Standards' standard sample No. 121a, which contains 0.361 per cent titanium.

$$\text{Factor} = \frac{0.361}{\text{dial reading}}$$

NOTE 8.—A graph (Fig. 2), showing the curve obtained on the Armco Research Klett-Summerson instrument, is attached for purposes of illustration. *It is to be understood, however, that this curve applies only to the Armco Research instrument and is not to be used with any other Klett-Summerson colorimeter. It is absolutely necessary that a curve be established for each individual instrument.*

COLORIMETRIC DETERMINATION OF PHOSPHORUS AS MOLYDIVANADOPHOSPHORIC ACID

SUBMITTED BY M. G. MELLON, PURDUE UNIVERSITY

1. Principle of Method.—The following procedure, based upon a study of various steels from the National Bureau of Standards, is recommended for the colorimetric determination of phosphorus in plain carbon steels and certain low-alloy steels.

2. Procedure.—(*a*) Weigh a 0.5-g. representative sample into a 150 ml. conical flask. Add 20 ml. of HNO_3 (1:2), and, after violent action ceases, boil for 2 min. to remove nitrous oxide fumes. Add 5 ml. of a freshly prepared 7.5 per cent aqueous solution of ammonium peroxydisulfate ($(NH_4)_2S_2O_8$) and boil 3 to 5 min. to destroy the excess.

(*b*) Add 10 ml. of 0.25 per cent ammonium vanadate solution to the hot steel solution and then cool to room temperature. Add 20 ml. of 5 per cent ammonium molybdate solution, mix thoroughly, and transfer the solution to a 100-ml. volumetric flask. Dilute to the mark, mix, and measure the color intensity by any suitable means. A blue filter with maximum transmission near 470 mμ is suitable for a filter photometer. With a spectrophotometer the best wave length is the range 460 to 480 mμ.

(*c*) The photometric calibration curve may be prepared by using a series of steels of known phosphorus content, or by adding known amounts of phosphorus to solutions of a single analyzed steel. Since Beer's law applies, one may extrapolate to concentrations of phosphorus below that of the standard. If several types of steels, having compositions not too different but giving different background colors, are to be analyzed, an average calibration curve may be prepared from the average of the results obtained. In any questionable case, however, the first alternative mentioned should be followed.

COLORIMETRIC DETERMINATION OF MOLYBDENUM IN ALLOY STEELS

SUBMITTED BY E. R. VANCE, TIMKEN ROLLER BEARING CO., STEEL AND TUBE DIVISION

1. *Introduction.*—The increasing demand for molybdenum steels, as well as the popularity of recently simplified photoelectric colorimeters, was responsible for the development of this method for the rapid colorimetric determination of molybdenum by means of a photoelectric colorimeter (Note 1). This method is less time-consuming, maintains the necessary accuracy, and eliminates the human error in color comparison. The method has been in use in the Timken laboratories for the past 3 yr. It is the fastest procedure known to this laboratory for the accurate determination of molybdenum in steel, requiring 7 min. to weigh the sample and complete the entire operation. It is possible to determine molybdenum in steel containing up to 6 per cent of this element by decreasing the sample as the percentage of molybdenum increases.

2. *Reagents:* (*a*) *Nitric-Sulfuric Acid Mixture.*—Add 1800 ml. of H_2SO_4 (sp. gr. 1.84), cautiously, to 6 liters of water, and then add 2800 ml. of HNO_3 (sp. gr. 1.42).

(*b*) *Hydrochloric Acid (1:5).*

(*c*) *Potassium Thiocyanate Solution (5 per cent).*—Dissolve 50 g. of KCNS in 1 liter of water.

(*d*) *Stannous Chloride Solution.*—Dissolve 500 g. of $SnCl_2$ in 400 ml. of HCl (sp. gr. 1.18) and add 1600 ml. of water.

3. *Procedure for Steels Containing up to 0.50 per cent of Molybdenum.*—(*a*) Transfer 0.1 g. of the sample to a 200-ml. Erlenmeyer flask. Add 6 ml. of the $HNO_3 - H_2SO_4$ mixture to dissolve. When in solution, rinse the inner walls of the flask with approximately 5 ml. of water from a wash bottle and boil the solution for 1 min.

(*b*) Add 30 ml. of HCl (1:5) and bring the solution to a boil (Note 2). Remove from the hot plate and place in running water until cold. Add 5 ml. of KCNS (5 per cent) and shake. Add 50 ml. of ether (Note 3), followed by 10 ml. of

$SnCl_2$ solution. The reduced iron will be colorless in solution, while the molybdenum produces an orange-red color, the intensity depending upon the amount present.

(*c*) Immediately transfer the solution to a 500-ml. separatory funnel, which is stoppered and shaken vigorously. Allow to stand until the ether and acid layers have separated. Drain and discard the lower aqueous solution, and transfer the remaining ether containing the extracted molybdenum to a 50-ml. volumetric flask. Fill the flask to the mark, if necessary, with ether and return the solution to the original 200-ml. Erlenmeyer flask. Shake to insure uniform mixing. First rinse, then fill a matching cell with the ether extracted. Insert the cell in the photoelectric colorimeter, obtain the dial reading, and convert to percentage of molybdenum from a chart previously prepared from a curve made by analyzing steels with known molybdenum contents (Note 4).

4. Procedure for Steels Containing up to 1.00 per cent of Molybdenum.—Determine molybdenum as described in Section 3, with the following modifications: Use 0.1 g. of the sample, treat with a double portion of KCNS and $SnCl_2$, and dilute the ether extract to 100 ml. in a volumetric flask. Multiply the colorimeter reading by 2.

5. Procedure for Steels Containing up to 6.00 per cent of Molybdenum.—Dissolve 0.1 g. of the sample in 15 ml. of aqua regia (2 parts of HCl to 1 part of HNO_3). Dilute to 500 ml. in a volumetric flask and draw off 25 ml. for a sample. Add 30 ml. of HCl (1:5) and complete the determination as described in Section 3 (*b*) and (*c*). The result multiplied by 20 equals the percentage of molybdenum.

6. Procedure for Steels Containing Tungsten and 6 per cent of Molybdenum.—Dissolve 0.1 g. of the sample in 20 ml. of H_2SO_4 (sp. gr. 1.84) and 4 ml. of H_3PO_4 (85 per cent). Oxidize with HNO_3 (sp. gr. 1.42) from a dropping bottle and boil. Dilute to 500 ml. in a volumetric flask and draw off a 25-ml. sample. Add 30 ml. of HCl (1:5) and complete the determination as described in Section 3 (*b*) and (*c*). The result multiplied by 20 equals the percentage of molybdenum.

EXPLANATORY NOTES

NOTE 1.—A Klett-Summerson photoelectric colorimeter, industrial model with adapter for test tube cells, is used for this work. The instrument employs a balanced circuit with two photocells, which eliminates any deflection due to a surge in the 110-v. power supply.

NOTE 2.—This method eliminates the necessity for fuming, and by the use of the more common acids the danger of fire and explosion is removed.

NOTE 3.—U.S.P. or "Purified" grade ether is used for extraction, since the separation is more rapid than with other extractants, and the ether requires no special treatment but is used as received.

NOTE 4.—Fading is not encountered, since it is not necessary to use color standards. Errors due to fatigue, eyestrain, and color blindness are no longer a problem with color matching being performed with a photoelectric colorimeter.

DETERMINATION OF PHOSPHORUS, MANGANESE, MOLYBDENUM, AND TITANIUM IN STAINLESS STEELS BY GLASS COLOR FILTER PHOTOMETRY

SUBMITTED BY W. J. BOYER, RUSTLESS IRON AND STEEL CORP.

All of the so-called photoelectric colorimeters can be used for measuring the transmission or density of the solutions obtained by following all the steps of the following recommended procedures for determination of phosphorus, manganese, molybdenum, and titanium by glass color filter photometry. The appropriate glass color filters for the determination of each particular element are indicated under the procedure for that element. Experiments for the development of the procedures were carried out with a solution thickness of approximately 12 mm. Supporting experimental data, spectrophotometric curves, and photometer calibration curves have all been investigated and will be presented in an early publication.

RECOMMENDED PROCEDURE FOR PHOSPHORUS

1. Apparatus: Glass Color Filter.—For the colorimetric determination of phosphorus in stainless steels the following combination of Corning glass color filters has been found useful; one No. 2412 (approximately 5.0 mm. thick) plus one No. 5551 (approximately 5.5 mm. thick).

2. Reagents: (*a*) *Sodium Sulfite Solution.*—Dissolve 100 g. of anhydrous Na_2SO_3 in 500 ml. of water and dilute to 1 liter. Filter the solution before use.

(*b*) *Hydrazine Sulfate Solution.*—Dissolve 1.5 g. of hydrazine sulfate in 1 liter of water.

(*c*) *Ammonium Molybdate Solution.*—Add 300 ml. of H_2SO_4 (sp. gr. 1.84) to 500 ml. of water and cool the solution to room temperature. Dissolve 20 g. of ammonium molybdate in the H_2SO_4 solution and dilute to 1 liter with water.

(*d*) *Ammonium Molybdate - Hydrazine Sulfate - Sodium Sulfite Reagent.*—Dilute 25 ml. of the ammonium molybdate solution to 60 ml. with water. Add 10 ml. of the hydrazine sulfate solution and 20 ml. of the Na_2SO_3 solution, and dilute to 100 ml. with water. This reagent is not stable and must be prepared as needed.

3. Procedure.—(*a*) Transfer a 0.050 g. sample (Note 1) to a 125-ml. Erlenmeyer flask and treat the sample with 10 ml. of a mixture of HNO_3 (sp. gr. 1.42) and HCl (sp. gr. 1.19) (1:1). Heat gently until solution of the sample is complete. Add 4 ml. of $HClO_4$ (sp. gr. 1.66) and evaporate until the $HClO_4$ vapors condence freely in the neck of the flask and all the chromium is oxidized to chromic acid.

(*b*) Cool the flask and its contents slightly, and add 10 ml. of water and 15 ml. of the Na_2SO_3 solution. Heat the solution to boiling and boil gently for not less than 1 min. and not more than 2 min. Cool the solution rapidly to 20 C. and then transfer it to a 50-ml. volumetric flask. Add 20 ml. of the ammonium molybdate - hydrazine sulfate - sodium sulfite reagent and dilute to the mark with distilled water. Mix the solution thoroughly.

(*c*) Transfer exactly 10 ml. of the solution to a clean, dry, colorimeter tube and measure the density due to the colored ions of chromium, nickel, iron, etc. To develop the blue phosphomolybdenum color, heat the colorimeter tube and its contents for not less than 8 min. and not more than 10 min. in boiling water. The heating is most conveniently done by immersing the colorimeter tube in 25 to 30 ml. of boiling water contained in a 125-ml. Erlenmeyer flask. After complete development of the blue phosphomolybdenum color by heating, cool the colorimeter tube and its contents rapidly to 20 C. and dilute to exactly 10 ml. with distilled water. Mix the contents of the colorimeter tube thoroughly. Measure the increase in density due to the blue phosphomolybdenum color. Subtract the colorimeter reading of the unheated solution from the colorimeter reading of the heated solution to obtain the density due to the blue phosphomolybdenum color.

(*d*) The percentage of phosphorus found in the steel sample must be corrected for the amount of phosphorus present in the reagents which are used. The reagents used must be checked periodically and the proper correction applied if the amount of phosphorus in them is found to vary. Two methods for determining this correction are as follows:

(*1*) By carrying a standard steel sample of a known phosphorus content through all the steps of Paragraphs (*a*) to (*c*), or

(*2*) By carrying all the reagents, without a steel sample, through all of the steps of Paragraphs (*a*) to (*c*).

EXPLANATORY NOTE

NOTE 1.—The usual amount of columbium and selenium found in certain types of stainless steel does not interfere in the determination of phosphorus by this method. Tungsten will not cause interference in the method as written when the amount present is less than 5 per cent.

RECOMMENDED PROCEDURE FOR MANGANESE

1. Apparatus: Glass Color Filter.—For the colorimetric determination of manganese in stainless steels, two different Corning glass color filter combinations have been found useful. For low manganese contents, where the greatest accuracy is desired, the following combination of Corning glass color filters has been found useful; one No. 3384 (approximately 3.0 mm. thick) plus two No. 4203 (approximately 4.0 mm. thick). For high manganese contents, where a greater deviation can be tolerated, the Corning glass color filter No. 5543 (approximately 4.0 mm. thick) has been found useful.

2. Reagents: (*a*) *Sulfuric Phosphoric Acid Mixture.*—Add 500 ml. of H_2SO_4 (sp. gr. 1.84) to 250 ml. of water, mix, and cool to room temperature. To the cooled solution, add 250 ml. of H_3PO_4 (sp. gr. 1.69).

(*b*) *Potassium Periodate Solution.*—Dissolve 5.0 g. of KIO_4 in 1 liter of distilled water. Filter the solution before use.

3. Procedure.—(*a*) Transfer a 0.050 g. sample (Note 1) to a 200-ml. Erlenmeyer flask and dissolve the sample by treating it with 10 ml. of a mixture of HNO_3 (sp. gr. 1.42) and HCl (sp. gr. 1.19) (1:1). After solution of the sample, add two drops of HF (sp. gr. 1.15) and 10 ml. of $HClO_4$ (sp. gr. 1.66) (1:1). Evaporate the solution until the $HClO_4$ vapors condense freely in the neck of the flask and all of the chromium is oxidized to chromic acid. Cool the flask and its contents and add 20 ml. of water, 20 ml. of $H_2SO_4 - H_3PO_4$ solution, and 10 ml. of KIO_4 solution. Bring the solution to a boil and continue the boiling for approximately 1 min.

(*b*) Cool the flask and its contents to room temperature. Transfer the solution to a 100-ml. volumetric flask, add an additional 20 ml. of $H_2SO_4 - H_3PO_4$ solution, and dilute to the mark with water. Mix the solution thoroughly. Transfer exactly 10 ml. of the solution to a clean, dry colorimeter tube and measure the density due to the colored ions of manganese, chromium, nickel, and iron. Record as reference plus color reading.

(*c*) To the colorimeter tube add two drops of HCl (sp. gr. 1.19). Mix the solution thoroughly and allow to stand for approximately 1 min. Measure the decrease in density due to the reduction of the colored manganese ion and record as the reference reading. Subtract the reading of the reference solution from the reading of the colored solution and multiply the difference reading by the factor previously established for the particular colorimeter and glass filter combination.

EXPLANATORY NOTE

NOTE. 1.—Tungsten, columbium, selenium, titanium, and moderate amounts of cobalt (less than 2.5 per cent) will cause no interference in the method as written.

RECOMMENDED PROCEDURE FOR MOLYBDENUM

1. Apparatus: Glass Color Filters.—For the colorimetric determination of molybdenum in stainless steels, two different Corning glass color filter combinations have been found useful. For low molybdenum contents, where the greatest accuracy is desired, the following combination of Corning glass color filters has been found useful; one No. 3389 (approximately 2.0 mm. thick) plus one No. 5543 (approximately 5.0 mm. thick). For high molybdenum contents, where a greater deviation can be tolerated, the following combination of Corning glass color filters has been found useful; one No. 3384 (approximately 3.0 mm. thick) plus two No. 4303 (approximately 4.0 mm. thick).

2. Reagents: (*a*) *Sodium Thiocyanate Solution.*—Dissolve 150 g. of NaCNS in 1 liter of distilled water. Filter the solution before use.

(*b*) *Stannous Chloride Solution.*—Dissolve 300 g. of $SnCl_2$ in 200 ml. of hot HCl (sp. gr. 1.19) and dilute to 1 liter with distilled water. Filter the solution before use. Add a few pieces of metallic tin to the filtered stock solution to prevent oxidation.

3. Procedure.—(*a*) For stainless steels containing selenium and more than 1 per cent copper, the procedure should be modified as indicated in Notes 1 and 2. Tungsten does not interfere if the amount present is less than 5 per cent.

(*b*) Transfer a 0.05 g. sample to a 200-ml. Erlenmeyer flask and dissolve the sample by treating it with 10 ml. of a mixture of HNO_3 (sp. gr. 1.42) and HCl (sp. gr. 1.19) (1:1). After solution of the sample, add two drops of HF (sp. gr. 1.15) and 10 ml. of $HClO_4$ (sp. gr. 1.66) (1:1). Evaporate the solution until the $HClO_4$ vapors condense freely in the neck of the flask and all of the chromium is oxidized to chromic acid. Cool the flask and its contents and add 25 ml. of water, 25 ml. of H_2SO_4 (sp. gr. 1.84) (1:1), and 25 ml. of $SnCl_2$ solution. Bring the solution to a boil and continue the boiling for not less than 2 min. and not more than 3 min.

(*c*) Cool the flask and its contents to room temperature, transfer the solution to a 100-ml. volumetric flask, and dilute to the mark with HCl (1:99). Mix the solution thoroughly (when selenium is present, see Note 1). Transfer exactly 10 ml. of the solution to a clean, dry colorimeter tube and measure the density of this solution. Record the density as the reference reading.

(*d*) To develop the orange colored molybdenum thiocyanate complex, add 1 ml. of NaCNS solution to the colorimeter tube from a burette and mix the solution thoroughly. From another burette, add 1 ml. of the $SnCl_2$ solution to the colorimeter tube and again mix the solution thoroughly. When more than 1 per cent of copper is present, the solution will develop a turbidity at this point and the procedure should be modified as directed in Note 2. Allow the color to develop for approximately 5 min. before measuring the increase in density due to the molybdenum thiocyanate complex.

(*e*) Subtract the reading of the reference solution from the reading of the colored solution and multiply the difference by the factor previously established for the particular colorimeter and glass filter combination.

EXPLANATORY NOTES

NOTE 1.—For stainless steels containing selenium the procedure as written must be modified as follows: Filter approximately 15 to 20 ml. of the solution through a dry, tight, filter paper. Transfer exactly 10 ml. of the filtered solution to a clean, dry, colorimeter tube and measure the density of this solution. Record the density as the reference reading. Develop the orange colored molybdenum thiocyanate complex as described in Section 3 (*d*).

NOTE 2.—When more than 1 per cent of copper is present, add to the colorimeter tube 0.1 g. of solid NaCNS. Mix the solution until the sodium thiocyanate has completely dissolved and then filter the contents of the tube through a dry, tight filter paper. Clean and dry the tube, transfer approximately 10 ml. of the filtered solution to the colorimeter tube, and measure the increase in density due to the molybdenum thiocyanate complex.

RECOMMENDED PROCEDURE FOR TITANIUM

1. Apparatus: Glass Color Filter.—For the colorimetric determination of titanium in stainless steels, the Corning glass color filter No. 5113 (approximately 4.0 mm. thick) has been found useful.

2. Reagent: Hydrogen Peroxide (30 per cent).

3. Procedure.—(*a*) Transfer a 0.050 g. sample (Note 1) to a 200-ml. Erlenmeyer flask and treat the sample with 10 ml. of a mixture of HNO_3 (sp. gr. 1.42) and HCl (sp. gr. 1.19) (1:1). Heat gently until the solution of the sample is complete. Add 10 ml. of $HClO_4$ (sp. gr. 1.66) (1:1), 5 ml. of H_3PO_4 (sp. gr. 1.69) (1:3), and two drops of HF (sp. gr. 1.15). Evaporate until the $HClO_4$ vapors condense freely in the neck of the flask and all of the chromium is oxidized to chromic acid.

(*b*) Cool the flask and its contents slightly and add 5 ml. of water to dissolve the salts. Reduce the chromic acid to the trivalent state by adding 5 ml. of water which has been saturated with SO_2. Bring the solution to a boil and continue the boiling until the excess of SO_2 has been expelled. Add 5 drops of HNO_3 (sp. gr. 1.42) to oxidize the iron to the trivalent state, and then add 10 ml. of H_2SO_4 (sp. gr. 1.84) (2:3). Allow the solution to boil for 1 min. more.

(*c*) Cool the solution to 20 C., transfer to a 25-ml. volumetric flask, and dilute to the mark with water. Mix the solution thoroughly. Transfer a portion of the solution to a clean, dry, colorimeter tube and measure the density due to the colored ions of chromium, nickel, and iron. Add two drops of H_2O_2 (30 per cent) to the solution in the colorimeter tube. Mix the solution thoroughly. Measure the increase in density due to the yellow titanium peroxide.

(*d*) Subtract the colorimeter reading of the unperoxidized solution from the colorimeter reading of the peroxidized solution and multiply the difference by the factor previously established for the particular colorimeter and glass filter combination.

EXPLANATORY NOTE

NOTE 1.—Residual amounts of columbium will cause no appreciable error for titanium in the method as written. In analyzing chromium-nickel-columbium bearing stainless steels for titanium, a positive error of approximately 0.04 to 0.05 per cent of titanium will be obtained. Vanadium will not interfere appreciably if the amount present is less than 0.15 per cent.

ROUND-TABLE DISCUSSION ON CENTRIFUGAL CASTINGS

SUMMARY OF PROCEEDINGS—PREPARED BY N. L. MOCHEL[1]

A round-table discussion on centrifugal castings was held jointly with the American Foundrymen's Association during the Annual Meeting of the Society, in New York City, on June 28, 1944. A. E. Schuh cooperated in the arrangements and in the procurement of discussion leaders.

It had been agreed that the discussion would be quite informal, and that no official record would be made of the various presentations. Tentatively, the discussion was to be a preliminary one to a possible later formal session on the subject.

Discussion Leaders Were:

T. S. Quinn, Treasurer, Lebanon Steel Foundry
A. E. Schuh, Director of Research, U. S. Pipe and Foundry Co.
John Howe Hall, Research Metallurgist, General Steel Castings Corp.
C. V. Nass, Foundry Div., Pettibone Mulliken Corp.
Col. H. H. Zornig, Ordnance Dept., Watertown Arsenal
J. T. MacKenzie, Chief Metallurgist, American Cast Iron Pipe Co.
A. P. Spooner, Metallurgical Engineer, Bethlehem Steel Co.

Many others joined in the discussions.

The discussions illustrated the three general methods of centrifugal casting, and introduced such terms as the "true centrifugal" method, which involves spinning the casting about its own axis and using centrifugal force to hold the metal to the wall of the mold, no matter whether the axis is horizontal, vertical or inclined; the "semi-centrifugal" method involving spinning the casting about its axis, in which the speed of rotation is lower than that above, and in which the rotation aids in flowing the liquid metal into all mold cavities; and the "centrifuging" method in which the molds are located in various desired positions and centrifugal force is used merely to provide liquid pressure.

The discussions served to leave an excellent impression of the extent to which the three methods are in use today. The semi-centrifugal and centrifuging methods are used widely in producing castings to existing specifications, and the application of these methods would appear to involve no modifications to existing specifications and testing practices. Product produced by the "true centrifugal" method has necessitated testing practices pertinent to the application of the product.

The use of the three methods for producing many of our war-time products was well illustrated, and such products are being put to the test, so to speak, and the future will depend upon the results.

A feeling came from the discussion that it would be worthwhile at a later time to arrange a planned formal session dealing with the subject.

---

[1] Manager, Metallurgical Engineering, Westinghoues Electric and Manufacturing Co., Philadelphia, Pa.

THE EFFECTS OF CERTAIN VARIATIONS IN CONSISTENCY AND CURING CONDITIONS ON THE COMPRESSIVE STRENGTHS OF CEMENT-LIME MORTARS

By G. J. Fink[1]

Synopsis

Compressive strength data are presented on a series of cement-lime-sand mortars in which the ratio of cement to lime ranged from 1:1/4 to 0:1, by volume, and in which the ratio of cementitious material (cement plus lime) to standard Ottawa sand was 1:3, by weight. The results show that, with two exceptions, the 28-day strengths of the cement-lime mortars of 75 per cent flow were higher than those of the mortars of 110 per cent flow, the differences increasing with the increasing cement content. The reverse was true in the case of the straight lime mortars.

Data are also presented showing the effects of different methods of curing on the compressive strengths of specimens of mortars. The results indicate that the strengths of the mortars containing the highest proportion of cement (1:1/4:3 by volume) were practically the same when the test specimens were cured for 28 days in the damp closet as when the specimens were cured for 7 days in the damp closet and 21 days in water, but that in the case of the mortars with lower ratios of cement to lime, the specimens cured for the full period in the damp closet had significantly higher strengths than those cured under the other condition. Curing for 7 days in the damp closet, 18 days in water, and 3 days in laboratory air produced specimens with much higher strength than curing by either of the other procedures.

In the absence of standard specifications for testing mixtures of cement and lime which are to be used in masonry mortars in various proportions, compression tests of such mixtures are sometimes made in accordance with either the Federal specification for masonry cement[2] or the corresponding specification of the A.S.T.M.[3] These specifications, however, are not in agreement as to the consistency (flow) of the mortar to be tested, and confusion is likely to arise in interpreting or comparing the test data. Published data on the compressive strengths of cement-lime mixtures when tested as masonry cements and on the effects of different consistencies on the resulting values are quite meager. Questions have also arisen as to the methods to be adopted for curing test specimens and as to what minimum values should be required for the compressive strengths of mortars made with masonry sand and containing various proportions of cement and lime. A study of methods of testing and of specifications for cement-lime mortars is one phase of the investigation being conducted under a fellowship established by the National Lime Association at the National Bureau of Standards, and the data presented here were obtained in the course of tests designed to provide further information on these questions. For convenience of discussion, the data are presented under two headings.

---

[1] Research Associate for Nat. Lime Assn. at the National Bureau Standards.

[2] Federal Specification for Cement Masonry, SS-C-181b, January 12, 1938.

[3] Standard Specifications for Masonry Cement (C 91 - 40) 1942 Book of A.S.T.M Standards, Part II, p. 7.

EFFECTS OF CONSISTENCY ON THE COMPRESSIVE STRENGTHS OF STANDARD SAND MORTARS

Materials:

Five limes, each representing a particular type, were included in the tests. These, supplied by the respective manufacturers, were designated as masons limes, and are identified as follows:

Nos. 1 and 2—High-calcium hydrated limes of different water retentivities.

No. 3—Regular dolomitic hydrated lime,

No. 4—Pressure-hydrated dolomitic lime, and

No. 5—Putty made from pulverized high-calcium quicklime.

One portland cement, supplied by the manufacturer as type I, and standard Ottawa silica sand, No. 20 to No. 30 sieve, were used in all mortars.

Each material conformed to the requirements of the current A.S.T.M. specifications for the particular product.

Proportions:

Since the common field practice is to mix cement and lime in bag or volume proportions, the two materials were proportioned in volume ratios and the resulting mixtures were tested as masonry cements. The required quantities for each mix were weighed, the amounts used being calculated on the assumption that 1 cu. ft. of cement weighs 94 lb. and 1 cu. ft. of lime 45 lb. The cement lime mixture was then combined with standard Ottawa sand in the proportion of 1:3 cementitious material to aggregate by weight. Straight lime mortars, 1:3 by weight, were also included. In the mortars containing quicklime putty an amount of putty was used which contained the weight of lime solids equivalent to the weight of dry hydrated lime used in the other mixes. The putty was made by slaking the quicklime in accordance with the manufacturer's directions.

Preparation and Testing of Mortar Specimens:

The mixing, molding, curing, and testing of the cement-lime mortars were performed in strict conformity with the procedures prescribed in the A.S.T.M. and Federal specifications for masonry cement. Twelve test specimens, six for test at each age, were made from each mortar at the different consistencies specified in each of the two specifications. The A.S.T.M. specification requires that the mortar consistency be such that the flow by the standard flow-table test is between 65 and 80 per cent. The flow of the mortars for duplication of this test was adjusted to a value of approximately 75 per cent (range 72 to 76). The Federal specification requires a mortar with a flow between 100 and 115 per cent. For duplication of this condition the mortar was adjusted to a flow of approximately 110 per cent (range 108 to 113). All operations were performed in a laboratory maintained at a temperature of 21 ± 2 C. and a relative humidity of 55 ± 5 per cent. The temperature in the damp closet was 21 ± 2 C. and the relative humidity was 95 ± 3 per cent.

The straight lime mortars were cured in the laboratory air. The cubes from limes Nos. 1, 2, and 3 were removed from the molds after 48 hr. Those from limes Nos. 4 and 5 were not sufficiently rigid to be removed at 48 hr. and were left in the molds for 4 days.

Results and Conclusions:

The average compressive strength values obtained for the six cubes of each mortar are presented in Table I and the over-all averages and ratios in Table II. Lime No. 4 was received too late to be included in the tests of the 75 per cent flow mortars and hence was omitted in calculating the averages in Table II.

TABLE I.—EFFECTS OF CONSISTENCY ON COMPRESSIVE STRENGTHS OF STANDARD SAND MORTARS (ONE PART CEMENTITIOUS MATERIAL TO 3 PARTS STANDARD OTTAWA SAND BY WEIGHT).
Strength values are the average for six 2-in. cubes.

Lime	Composition of Cementitious Material, volume ratios cement: lime	Initial Flow 75 per cent			Initial Flow 110 per cent		
		Water, per cent[a]	Compressive Strength, psi.		Water, per cent	Compressive Strength, psi.	
			7 days	28 days		7 days	28 days
No. 1. High-calcium hydrated....	1:¼	11.2	3680	5225	12.5	2630	4165
	1:1	13.9	2205	2950	15.7	1480	2235
	1:2	15.9	1085	1350	17.5	615	1230
	1:3	18.0	575	635	18.6	415	790
	0:1	20.9	65	125	23.2	60	325
No. 2. High-calcium hydrated....	1:¼	11.0	3800	5440	12.3	2650	4025
	1:1	13.0	2310	3115	13.8	1720	2925
	1:2	14.0	1305	1615	15.1	1055	1690
	1:3	15.0	755	1010	16.6	560	965
	0:1	19.5	170	305	21.6	160	485
No. 3. Regular dolomitic hydrated.	1:¼	11.1	3575	5065	12.3	2505	3835
	1:1	12.0	2475	3250	13.9	1590	2665
	1:2	13.3	1420	1985	14.6	1125	1630
	1:3	13.9	720	1155	15.1	675	1100
	0:1	17.2	150	375	18.0	190	565
No. 4. Pressure-hydrated dolomitic	1:¼	....	....	....	12.5	2655	4300
	1:1	....	....	....	14.3	1800	2540
	1:2	....	....	....	16.6	760	1345
	1:3	....	....	....	16.7	510	1000
	0:1	....	....	....	21.9	80	335
No. 5. High-calcium quicklime putty..........................	1:¼	10.2	3845	5120	12.2	2470	3685
	1:1	11.2	1955	2745	13.2	1550	2530
	1:2	11.3	1135	1595	14.1	820	1355
	1:3	11.4	685	865	14.6	450	830
	0:1	13.5	75	150	18.5	100	335

[a] Basis total weight of dry materials. In case of quicklime putty this includes water in putty.

TABLE II.—OVER-ALL AVERAGES AND RATIOS CALCULATED FROM VALUES IN TABLE I FOR MORTARS CONTAINING LIMES NOS. 1, 2, 3, AND 5.

Composition of Cementitious Material, Volume Ratios Cement: Lime	Initial Flow 75 per cent					Initial Flow 110 per cent					Strength at 75-flow / Strength at 110-flow	
	Average Compressive Strength, psi.		7-day Strength / 28-day Strength			Average Compressive Strength, psi.		7-day Strength / 28-day Strength				
	7 days	28 days	Max.	Min.	Avg.	7 days	28 days	Max.	Min.	Avg.	7 days	28 days
1:¼...........	3725	5215	0.75	0.70	0.72	2565	3930	0.66	0.63	0.65	1.45	1.33
1:1............	2235	3015	0.76	0.71	0.74	1590	2590	0.66	0.59	0.61	1.41	1.16
1:2............	1235	1635	0.81	0.71	0.74	905	1475	0.69	0.50	0.61	1.36	1.11
1:3............	635	915	0.90	0.62	0.70	525	920	0.61	0.53	0.57	1.21	0.99
0:1............	115	240	0.56	0.40	0.48	130	425	0.34	0.19	0.31	0.88	0.56

The variation among the compressive strength values for each set of six cubes was slightly greater in the case of the cement-lime mortars of 75 per cent flow than for those of 110 per cent flow, the average coefficient of variation for the former being 3 per cent and for the latter 2.5 per cent. This indicates a somewhat greater uniformity of the specimens made from the mortars of the higher flow. It was somewhat easier to obtain reproducible flow measurements with the mortars at the higher flow, and at this consistency the molding of the cubes was simpler.

The 7-day compressive strength values for all of the cement-lime mortars adjusted to a flow of 75 per cent were higher than the corresponding 7-day values obtained for specimens from mortars adjusted to a flow of 110 per cent. With but two exceptions out of the 20 individual mortars, the same is true for the 28-day strengths. The effect of differences in flow in producing differences in compressive strengths of the cement-lime mortars decreased with increasing lime content of the mortar, there being no significant or consistent difference between 28-day values for the 1:3 cement-lime mixtures molded at the two different flows.

The compressive strengths of the straight lime mortars at 28 days were, however, much higher for specimens molded at flows of 110 per cent than for the corresponding specimens molded at flows of 75. The effect of molding consistency on the strengths of the straight lime mortars at 7 days appeared to be entirely random, and for this reason little significance can be attached to the averages of the 7-day strengths recorded in Table II for these particular mortars.

The ratios of the 7-day strengths to the 28-day strengths show a rather large spread among the mortars from the different limes, but the averages recorded in Table II indicate that the ratio is significantly higher for the mortars of the lower flow. That the trend is for increased flow to lower the ratio was also indicated by the results of cooperative tests of masonry mortars reported by A.S.T.M. Committee C-12 on Mortars for Unit Masonry.[4]

It is of interest to note that all of the cement-lime mixtures tested, in which the ratio of cement to lime was 1:2, by volume, or higher, fulfilled the strength requirements for type II masonry cement (500 psi. for 7-day and 1000 psi. for 28-day) specified in the Federal specification, and that all the mixtures, including those with a cement-lime ratio of 1:3, met the strength requirements (350 and 600 psi., respectively) of the A.S.T.M. specifications.

The very appreciable differences between the compressive strength values of most of the mortars of the two different consistencies used in these tests, however, make it obvious that any comparative tests of cement-lime mixtures should be made on mortars adjusted to the same flow and it would appear that possible confusion would be avoided in the testing of cementitious materials if the A.S.T.M. and Federal specifications for masonry cement were in agreement on the consistency of the mortar to be tested. As a result of the experience with mortars gained from these tests, which indicates that flow determinations are easier to duplicate and test specimens are more uniform with the mortars of the higher flow, it is suggested that a flow of 110 ± 5 per cent be adopted as standard for the testing of cement-lime mixtures.

EFFECTS OF CERTAIN VARIATIONS IN CURING CONDITIONS ON COMPRESSIVE STRENGTHS OF MASONRY SAND MORTARS

The use of a 28-day damp closet cure in the testing of cement-lime mortars has been advocated[5] as a substitute for the combined damp closet and water cure prescribed in the standard specifications for masonry cement, and the following tests were made to compare the two methods. A limited number of tests were also made to demonstrate the effect of the water content at the time of test on the compressive strength of the test specimens.

---

[4] *Proceedings*, Am. Soc. Testing Mats., Vol. 42, p. 266 (1942).

[5] Howard R. Staley, "Curing of Masonry Mortars," *Proceedings*, Am. Soc. Testing Mats., Vol. 42, p. 762 (1942).

Materials:

Limes Nos. 1, 3, 4, and 5 described above and the same portland cement were used in this series of tests. The aggregate, however, was Potomac River building sand of the following screen analysis:

Passing No.	4 Sieve	100.0 per cent
Passing No.	8 Sieve	97.2 per cent
Passing No.	16 Sieve	91.6 per cent
Passing No.	30 Sieve	66.3 per cent
Passing No.	50 Sieve	19.5 per cent
Passing No.	100 Sieve	3.0 per cent

Fineness modulus = 2.22

TABLE III.—EFFECTS OF METHODS OF CURING ON COMPRESSIVE STRENGTHS OF MASONRY SAND MORTARS.

Strength values are the averages for 6 cubes.

Composition of Mortar, proportions by volume Cement: Lime: Sand	Lime	28-day Compressive Strength, psi.		Increase in Strength of Cure No. 2 Over Cure No. 1, per cent	28-day Compressive Strength, psi., Cure No. 3 (7 days in damp closet + 18 days in water + 3 days in air)	Increase in Strength of Cure No. 3 Over Cure No. 1, per cent
		Cure No. 1 (7 days in damp closet + 21 days in water)	Cure No. 2 (28 days in damp closet)			
1:¼:3	No. 1	5155	5175	+0.3	6155	+19.3
	No. 3	5610	5645	+0.6	6735	20.0
	No. 4	5520	5595	+1.3	6880	24.6
	No. 5	5635	5445	−3.3	6620	17.5
	Average	5480	5465	−0.3	6595	20.3
1:1¼:6	No. 1	1410	1460	+3.5	1805	+27.9
	No. 3	1625	1825	12.3	2250	38.4
	No. 4	1550	1650	6.5	2160	39.3
	No. 5	1225	1345	9.8	1930	57.5
	Average	1450	1570	8.2	2035	40.4
1:2½:9	No. 1	485	515	+6.2	640	+31.5
	No. 3	690	765	10.8	1030	48.9
	No. 4	575	610	6.1	875	52.3
	No. 5	445	480	7.9	730	64.5
	Average	550	590	7.7	820	49.1

Proportioning and Mixing:

The cement, dry hydrated lime or quicklime putty, and the sand were proportioned by volume, but the quantities of materials required for each mix were determined by weight on the basis of the following values for the weight per cubic foot for each material: cement, 94 lb.; hydrated lime, 40 lb.; quicklime putty, 86 lb. Eighty pounds of dry sand was used as the equivalent of 1 cu. ft. of damp loose sand. The value of 40 lb. for the weight of 1 cu. ft. of hydrated lime instead of 45 lb. as used in the previous series of tests was used in this series in order to conform to the values suggested in the code recently approved by the American Standards Association.[6] The quicklime putty contained 48 per cent solids and 1 cu. ft. weighed 86 lb.

The mixing procedure was the same as that described in the two specifications for masonry cement,[2,3] but the consistency of the mortars was adjusted to a flow of between 107 and 114 per cent.

Curing:

Four different conditions of curing were employed as follows:

1. 7 days in damp closet plus 21 days in water.
2. 28 days in damp closet.

---

[6] American Standard Building Code Requirements for Masonry, A-41.1-1944.

3. 7 days in damp closet plus 18 days in water plus 3 days in laboratory air.
4. 28 days in laboratory air.

The conditions in the damp closet were automatically controlled at a temperature of 21 ± 2 C. and a relative humidity of 95 ± 3 per cent. There was no fog in this cabinet. The conditions in the laboratory were maintained at a temperature of 21 ± 2 C. and a relative humidity of 55 ± 5 per cent. The temperature of the water in which the cubes were stored was 21 ± 2 C.

Six cubes of each of the mortars of the three proportions listed in Table III were cured under each of the first three conditions, and six cubes of the 1:4:15 mortars (Table VI) were cured under each of conditions Nos. 2 and 4. All specimens of the first three proportions were removed from the molds at the end of 48 hr. All of the specimens of the 1:4:15 mortars were left in the molds for 72 hr. because some of those in the damp closet were not sufficiently strong to be handled at 48 hr. Only the 28-day strengths were determined.

TABLE IV.—WEIGHTS OF CUBES AT TIME OF TEST (CURES NO. 1 AND 2).

Lime	Cement, Lime, Sand by Volume, $1:\frac{1}{4}:3$			Cement, Lime, Sand by Volume, $1:1\frac{1}{4}:6$			Cement, Lime, Sand by Volume, $1:2\frac{1}{2}:9$		
	Average Weight of Cubes, g.		Difference, g.	Average Weight of Cubes, g.		Difference, g.	Average Weight of Cubes, g.		Difference, g.
	Cure No. 1	Cure No. 2	Cure No. 1 minus Cure No. 2	Cure No. 1	Cure No. 2	Cure No. 1 minus Cure No. 2	Cure No. 1	Cure No. 2	Cure No. 1 minus Cure No. 2
No. 1.........	285.2	286.1	−0.9	273.2	271.2	+2.0	265.3	266.9	−1.6
No. 3.........	289.5	287.2	+2.3	279.9	278.1	+1.8	276.2	276.5	−0.3
No. 4.........	289.3	288.7	+0.6	275.4	276.4	−1.0	271.7	270.6	+1.1
No. 5.........	290.9	289.2	+1.7	274.1	273.6	+0.5	268.4	268.6	−0.2

Discussion of Results:

The results of the compressive strength tests are presented in Tables III and VI. Each of the values recorded is the average for six cubes.

It is evident that for mortars of the proportion $1:\frac{1}{4}:3$ the strengths of the specimens cured under the conditions specified in A.S.T.M. Specifications C 91 (cure No. 1) were practically the same as the strengths developed by curing for the full period in the damp closet (cure No. 2).

On the other hand, the strengths of the mortars of the proportions $1:1\frac{1}{4}:6$ and $1:2\frac{1}{2}:9$ were significantly higher when they were cured for 28 days in the damp closet (cure No. 2) than when cured for 7 days in the damp closet and 21 days in water (cure No. 1). A comparison of the weights of the cubes at the time of test, as recorded in Table IV, shows that there were no appreciable differences in the weights of the cubes cured by the two different methods. This would indicate that the specimens cured under the two different conditions had approximately the same moisture content at the time of test. Although the differences between the strengths developed by the different curing conditions are considerably less than those reported by Staley,[5] they are, nevertheless, in the same direction and, while the percentage increases of the damp cure strengths (cure No. 2) over the water cure strengths (cure No. 1) are not greatly in excess of the expected deviations in the averages of this number of tests, the consistency of the results gives assurance of their significance.

The effect of drying on the strength of the specimens is shown by a comparison of the strengths of the cubes cured under

TABLE V.—WEIGHTS OF CUBES (CURE NO. 3).

Lime	Cement, Lime, Sand by Volume, 1:¼:3			Cement, Lime, Sand by Volume, 1:1¼:6			Cement, Lime, Sand by Volume, 1:2½:9		
	Average Weights of Cubes, g.		Loss Resulting from 3 days in Air, per cent	Average Weights of Cubes, g.		Loss Resulting from 3 days in Air, per cent	Average Weights of Cubes, g.		Loss Resulting from 3 days in Air, per cent
	On Removal from Water	After 3 days in Air		On Removal from Water	After 3 days in Air		On Removal from Water	After 3 days in Air	
No. 1	286.3	278.6	2.7	272.3	256.3	5.8	265.5	241.7	8.9
No. 3	289.0	281.1	2.7	278.5	262.1	5.8	276.4	253.8	8.2
No. 4	289.4	280.2	3.2	275.9	256.7	6.9	271.0	246.9	8.8
No. 5	289.7	280.5	3.2	274.4	251.5	8.3	269.1	239.9	10.8
Average	....	....	2.9	....	....	6.7	....	....	9.2

condition No. 1 with those cured under condition No. 3 (Table III). In the latter case, the cubes were cured the same as in No. 1 up to the age of 25 days and were then taken from the water and stored for 3 days in the laboratory air. In Table V are recorded the average weights of the cubes of each mortar at the time they were taken from the water and the corresponding weights after 3 days exposure to the air. The percentage loss in weight resulting from the 3 days drying increased with increasing proportions of lime. As shown in Table III, the strengths of the cubes from cure No. 3 were very much higher than the strengths of the cubes from either cure No. 1 or No. 2. The percentage increases in strength resulting from drying were greater with increasing lime content of the mortars and were approximately proportional to the losses in weight resulting from drying.

As shown in Table VI, the mortars of the proportion 1:4:15 which were cured in laboratory air (cure No. 4) developed strengths much higher than those cured in the damp closet. As would be expected, the weights of the air-cured specimens were much less than the weights of the specimens cured in the damp closet, but there is no rational relation between the differences in weights and the differences in strengths. Published data[7] show that curing in water gives higher strengths than curing in air for mortars with cement-lime ratios of 1:1 or 1:1¼, but no comparisons of the relative effects of water curing, damp closet curing, and air curing on the strengths of mortars with cement-lime ratios of 1:2½ are known to the author. Therefore, it is not to be assumed that air curing would be satisfactory for mortars containing higher proportions of cement to lime than 1:4, although the data reported in Table VI do show that air curing was favorable to mortars of this particular ratio. However, it may be noted in this connection that the percentage increase in the strength of the 1:4 ratio mortars obtained by air curing is less than the percentage increase resulting from the use of cure No. 3 compared with cure No. 1 for the 1:2½ mortars (Table III).

TABLE VI.—COMPRESSIVE STRENGTHS AND WEIGHTS OF CUBES OF 1:4:15 MORTARS.

Lime	28-day Compressive Strength			Weights of Cubes at Time of Test		
	Damp Closet, Cure No. 2, psi.	Air Cure No. 4, psi.	Increase, Cure No. 4 over No. 2, per cent	Cure No. 2, g.	Cure No. 4, g.	Difference Basis Cure No. 2, per cent
No. 1	220	255	16.0	265.7	231.3	12.9
No. 3	260	370	42.3	272.7	242.1	11.2
No. 4	205	295	43.9	265.9	231.8	12.8
No. 5	170	225	32.3	263.3	228.9	13.0

---

[7] See, for example: A. H. Stang, D. E. Parsons and J. W. McBurney "Compressive Strength of Clay Brick Walls," *Journal of Research*, Nat. Bureau Standards, Vol. 3, No. 4, p. 531 (1929), and C. C. Fishburne, D. Watstein and D. E. Parsons, "Water Permeability of Masonry Walls," Building Materials and Structures Report BMS7, Nat. Bureau Standards (1938).

With relation to specification requirements, it may be pointed out that the minimum 28-day compressive strength values for the four types of mortars established by the American Standard code requirements for masonry[6] are 2500, 600, 200, and 75 psi., whereas the lowest values obtained for the corresponding mortars in the present tests were, respectively, 5155, 1225, 445, and 225 psi. Other investigators[4, 7] have reported values for some of the mortar types which are more nearly comparable with the Code values, but in many cases the conditions of test were not the same as those specified in the code and were such as to contribute to lower strength values. It is also true that only one cement and one sand were used in the present tests and that the absolute extremes of proportions were not reached. However, since these tests include a fair cross-section of masons lime, the indications are that the values fixed by the code may be somewhat lower than necessary to admit cement-lime mortars made from the majority of commercial limes, combined with cement and sand similar to those used in these tests.

The results of the tests indicate the need for further information on the effects of variations in the damp-closet conditions and of the moisture content at the time of test on the compressive strength of specimens of the various mortars. Additional tests which should contribute further data are under way.

DISCUSSION

Mr. B. E. Kester.[1]—We were asked to duplicate some of Mr. Fink's work on weight proportioning of cement-lime mortars in comparison to present volume proportioning. In mixtures with cement-lime ratios of 1:2 and 1:3 we were in very close agreement with Mr. Fink's values both at a flow of 75 and a flow of 110. Our strength increase at a flow of 75 was of the same magnitude as that reported.

In the 1:½ and 1:¼ ranges we found that the strengths we obtained were radically lower. We found that the portland cement used affected our results. Our tests were started with one brand of cement and owing to a shortage of cement were completed with a second brand, both brands being type I cements. The consistencies of the two materials in cement lime-mortar mixes varied as much as 10 per cent with, of course, an equivalent variation in strength. I think we ought to consider seriously the portland cement we use in making these tests before we rely too much on data from these tests.

As a matter of interest we made comparisons of damp closet curing and regular A.S.T.M. moist air and water curing. We found that with normal dolomitic hydrates—all of our work was confined to dolomitic hydrates—an increase in strength of 10 to 15 per cent was gained by the damp closet curing. Pressure hydrated dolomites, however, are unaffected by the difference in curing. Actual data gave lower 28-day strengths for damp closet curing, though all values were within allowable experimental error. Thus in the development of pressure hydrates, little good can be expected by substitution of damp closet curing. We did not try the 3-day period in dry air reported by Mr. Fink, though this would appear to be a comparison between wet and dry strengths rather than a better curing condition.

There was one other interesting factor in this study, and that was the effect of using composited job sand in comparison to Ottawa testing sand. To obtain a composite job sand, we took A.S.T.M. Tentative Specifications for Aggregate for Masonry Mortar (C 144 – 42 T),[2] split the fineness values exactly through each extreme and made a sand having that fineness gradation.

Compressive strength cubes made using this sand had a 30 per cent higher 7-day strength than cubes made with standard Ottawa testing sand and the 28-day strengths were about 10 per cent higher for composite sand.

In the American Standard code for masonry materials, the cement-lime mortar tests are based on volume proportions. The volumes, however, are based on assumed weights. The weights given are 94 lb. per cu. ft. for portland cement, 40 lb. per cu. ft. for hydrated lime and 80 lb. per cu. ft. for sand. Chicago sands are heavier than this assumed weight and range from 90 to 100 lb. per cu. ft. However, we made a comparison between the volume basis as given in the code and the proposed weight basis given by Mr. Fink. As can be foreseen from the various proportioning, the code volumes using assumed weights gave higher strengths than true volume relationships, but considerably lower strengths than the weight relationship of 3 parts sand to 1 part cementitious material.

---

[1] Research Engineer, Research and Development Dept., Research Labs., United States Gypsum Co., Chicago, Ill.

[2] 1942 Book of A.S.T.M. Standards, Part II, p. 1105.

TABLE I.—EFFECT OF METHOD OF PROPORTIONING ON COMPRESSIVE STRENGTH OF 2-IN. MORTAR CUBES.

Proportioned by Weight, 1 Cementitious to 3 Parts of Standard Ottawa Sand					Proportioned by Volume; Brick Sand Fabricated to Arbitrary Grading[a]				Percentage Change in Compressive Strength Due to Proportion by Weight	
Lime	Composition of Cementitious Material. Volume Ratios, Cement: Lime	Initial Flow 106 to 117 per cent			Volumetric Ratios,[b] Cement: Lime: Sand	Initial Flow 111 to 116 per cent				
		Water, per cent	Compressive Strength, psi.			Water, per cent	Compressive Strength, psi.			
			7 days	28 days			7 days	28 days	7 days	28 days
No. 2 High calcium hydrate	1:¼	12.3	3565	5110	1:¼:3	14.4	3470	5105	+3	0
	1:1	14.5	1940	3020	1:1 :5	15.8	1260	2180	+54	+38
	1:2	16.3	830	1425	1:2 :7.5	16.0	560	955	+48	+49
	1:3	18.2	520	830	1:3 :10	16.5	255	420	+104	+98
	0:1	23.9	45	115	0:1 :2.5	19.6	90	180	−50	−36
No. 55 Pressure-hydrated dolomitic	1:¼	13.0	3435	4760	1:¼:3	13.8	3705	5970	−73	−20
	1:1	15.7	1710	2620	1:1 :5	15.3	1320	2065	+29	+27
	1:2	18.5	635	1160	1:2 :7.5	16.1	560	895	+13	+29
	1:3	18.9	440	860	1:3 :10	16.6	310	475	+42	+81
	0:1	26.0	40	80	0:1 :2.5	19.1	110	130	−63	−38
No. 49 Pressure-hydrated dolomitic	1:¼	12.4	3530	4660	1:¼:3	13.6	3805	5940	−72	−21
	1:1	14.4	2245	2910	1:1 :5	15.7	1375	2100	+63	+38
	1:2	15.9	1000	1460	1:2 :7.5	17.6	495	850	+102	+72
	1:3	17.1	615	1000	1:3 :10	17.7	260	415	+136	+140
	0:1	21.2	65	125	0:1 :2.5	20.5	110	160	−41	−28
No. 13 Regular dolomitic	1:¼	12.2	3795	5295	1:¼:3	15.2	3895	5355	−2.5	−1.1
	1:1	14.6	1875	2740	1:1 :5	16.3	1515	2025	+24	+35
	1:2	16.3	925	1635	1:2 :7.5	17.5	525	815	+75	+100
	1:3	16.2	445	825	1:3 :10	19.0	265	415	+68	+99
	0:1	22.4	145	255	0:1 :2.5	26.2	50	95	+190	+168

[a] The proportions given were based on cement at 94 lb., lime at 45 lb. and sand at 95 lb. per cu. ft.
[b] Volumetric ratios approx. 3 sand to 1 cementitious if sand is taken as 80 lb. per cu. ft.

These data, unfortunately, have not yet been prepared for presentation, but will be submitted to the Society's Committee C-7 on Lime at such time as they have been completely organized.

MR. HOWARD R. STALEY[3] (*presented in written form*).—It is apparent that one of the chief reasons that the subject of masonry mortars remains controversial is due to the lack of sufficient correlative information such as presented in this paper by Mr. Fink. For example, few have realized the full significance of the discrepancy between the method of testing lime-cement mortars, proportioned by volume, and masonry cement mortars, at a lower flow, proportioned on a weight basis. The data emphasize the fact which has long been known that masonry cements, which were the equivalent of 1:2 or 1:3 cement-lime mixtures, have been allowed on jobs where the equivalent lime-cement mixture would not be allowed because, for purposes of test the masonry cement was proportioned by weight while the lime-cement mixtures were proportioned by volume.

Data are given in the accompanying Table I which show further the differences that can be expected from the two methods of proportioning. All specimens were cured in a damp closet at 70 F. and 90 per cent relative humidity, with no fog or spray of water present. It should be pointed out that sand proportions used in the volumetric relations are very closely equivalent to three parts of sand per part of cementitious material when the dry sand in a cubic foot is considered to be 80 lb. The brick sand was fabricated according to the grading previously used.[4]

---

[3] Assistant Professor of Building Construction, Massachusetts Institute of Technology, Cambridge, Mass.

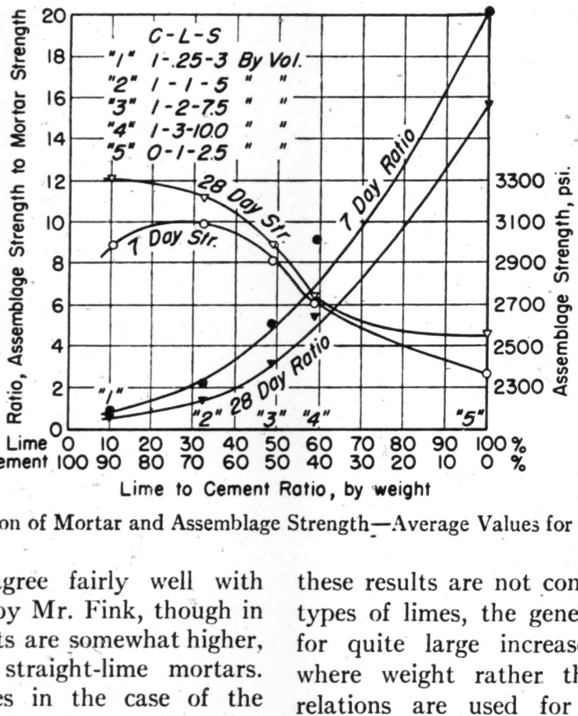


Fig. 1.—Relation of Mortar and Assemblage Strength—Average Values for Nine Limes.

These data agree fairly well with those presented by Mr. Fink, though in general the results are somewhat higher, except for the straight-lime mortars. The discrepancies in the case of the latter mortars cannot be explained but may have been due to a lower relative humidity during storage in the laboratory, which was on the order of 25 to 30 per cent. In the case of the mortars proportioned by volume, strengths as high as or higher than those obtained by Mr. Fink with cure No. 3, were obtained by curing in the damp room, except for the 1:¼:3 proportion. The strengths of this latter proportion are high enough to be eliminated as a controlling influence in the decision as to best curing conditions. In my opinion, water storage of any masonry mortar is not necessary for the development of optimum strength.

Given in the last two columns of Table I are the percentage changes in strength resulting from the difference in method of proportioning. While these results are not consistent with all types of limes, the general tendency is for quite large increases in strength where weight rather than volumetric relations are used for proportioning. These results also show that where the proportioning was done by weight, a ratio of cement to lime proportion of 1:2 by volume, or higher, resulted in strengths that fulfilled the requirements of the Federal specifications for type II masonry cement, and the cement to lime proportion of 1:3, by volume, or higher resulted in strengths that fulfilled the requirements of the A.S.T.M.

---

[4] Howard R. Staley, "Curing of Masonry Mortars," *Proceedings*, Am. Soc. Testing Mats., Vol. 42, p. 762 (1942).

Standard Specifications for Masonry Cement (C 91 – 40).[5]

The results reported above as well as those reported by Mr. Fink show that some serious consideration should be given to modification of testing methods for lime-cement mortars in order that data obtained with any type of masonry mortar will be more nearly comparable. For purposes of test, personal preference would dictate that the standard sand mortar be used and that the proportions be specified by weight, rather than by volume. Since the A.S.T.M., Federal and American Standard code requirements for masonry cements are based largely upon data derived from measurements on mortars proportioned on the weight basis, such a procedure as the foregoing would cause the least change and confusion regarding existing requirements. As a matter of fact, the testing of mortars in cubes gives only a relative figure that does not have a great deal of significance as regards the strength of the masonry.

Graphical presentation of the data to illustrate the above point is given in the accompanying Fig. 1. The strength of "two-bat" assemblages are plotted as well as the ratio of assemblage strength to mortar cube strength. For the assemblages, sand-lime brick were halved and the two halves were used to make up an assemblage with a $\frac{1}{2}$-in. mortar joint. The brick used had an average compressive strength of 4000 psi. The assemblages were cured at 70 F. and 90 per cent relative humidity, the same as the mortar cubes.

While the absolute values obtained are not pertinent in this discussion, it is interesting to note that the weakest mortar produced an assemblage strength of over 2500 psi. The significant fact is that the relative contribution of the mortar to the masonry strength is in the inverse direction to the trend of the mortar cube strength and a much better idea is obtained as to the relative value of the mortar in its ultimate application. The chief argument presented against the use of an assemblage test, rather than a mortar cube test, has been the difficulty of obtaining a suitable, reproducible, unit to use in conjunction with such a test. However, a large number of tests on commercially produced sand-lime brick have shown them to be quite uniform in characteristics and it is certain that if the process of proportioning and manufacturing were closely controlled, a product could be economically produced that had the desired characteristics and uniformity. The results obtained with these assemblage tests indicate that serious consideration should be given to the possibility of the use of such a test for evaluating mortars.

The results obtained by Mr. Fink on the rate of drying of cubes are interesting and pertinent beyond the present application of the data. The durability of masonry walls that are built of materials that endure in cold climates in spite of accelerated freezing and thawing test results to the contrary, can be explained largely on the basis of rapid loss of water. That is, the mortars do not remain in a relatively saturated state for any length of time and are therefore not harmed by freezing as much as one which retains absorbed water and dries out relatively slowly.

MR. G. J. FINK[6] (*author's closure, by letter*).—Mr. Kester found that the strengths of the pressure hydrated dolomitic limes which he tested were not affected by the differences in curing conditions. Our results with the one pressure hydrated lime, No. 4, show increases of 6.5 and 6.1 per cent, respectively, for the 1:1¼:6 and the 1:2½:9 mortars. While these increases are not large, they are, as we pointed out, appreciably greater than the coefficients of variation among the six cubes of any batch and we believe that they are significant with respect to this particular lime. Other pressure hydrated limes might very well fail to show such differences.

---

[5] 1942 Book of A.S.T.M. Standards, Part II, p. 7.

[6] Research Associate for National Lime Assn., at the National Bureau of Standards.

Relative to the tests on the effects of a 3-day drying (cure No. 3), we wish to make it clear that these tests were made only for the purpose of demonstrating the effects of differences in the moisture content and of variations in conditions of curing on the strengths and that the procedure is not recommended as a standard method of test.

Mr. Kester's higher strength values on mortars made with the well-graded Chicago sand would be expected because it is a well established fact that proper grading of a good sand contributes to appreciable increases in the strength values of mortars. The values for mortars made with the Chicago sand should also be higher than our values for the masonry sand which we used. The grading of the latter sand is far from the optimum.

COMPARATIVE TESTS OF 52 BRANDS OF PORTLAND CEMENT FROM 15 COUNTRIES

By Eugene V. Barrett[1]

Synopsis

This paper presents the results of comparative chemical and physical tests made on 52 brands of portland cement from 15 countries and includes the results of tests of 90 samples of one of these brands of cement that contained from 5.5 per cent to 9.6 per cent magnesium oxide (MgO). The investigation was started early in 1938, and cement was tested from Yugoslavia, Belgium, Germany, United States, Holland, France, England, Japan, Venezuela, Norway, Poland, Spain, China, Denmark, and Sweden.

The tests included tension tests on 7- and 28-day briquets, fineness, time of set, steam soundness, autoclave expansion, chemical analysis, and compression tests on 6 by 12-in. concrete cylinders made so that the cement was the only variable. The test methods were for the most part those recommended by the A.S.T.M.

Test results indicate that the expansion in the autoclave test does not bear any relation to the total MgO content of a cement. The 7-day briquet strengths bear some relation to constant water-cement ratio concrete cylinder strengths but cannot be considered as a reliable index of cylinder strength. The 28 day briquet strengths bear no relation to cylinder strengths. Most of the 52 brands of portland cement tested complied with A.S.T.M. specifications effective at the time the cements were tested, and several countries produced excellent quality portland cement.

An investigation of the portland cements imported into or produced in Venezuela was begun early in 1938. The tests were made in the Materials Testing Laboratory of the Ministry of Public Works, and the results of the investigation were used in preparing a specification to cover all portland cement bought by the Ministry.

The various cements were numbered from 1 to 52 as follows:

Nos. 1 to 3 were from Holland,
Nos. 4 to 10 from Belgium,
Nos. 11 to 19 from Germany,
Nos. 20 to 23 from France,
Nos. 24 to 31 from Yugoslavia,
Nos. 32 to 35 from United States,
Nos. 36 and 37 from Venezuela,
No. 38 from Sweden,
No. 39 from Denmark,
Nos. 40 to 42 from Japan,
Nos. 43 and 44 from Poland,
Nos. 45 and 46 from Norway,
Nos. 47 and 48 from Spain,
No. 49 from China, and
Nos. 50 to 52 from England.

The tests included 7- and 28-day briquets, fineness, time of set, steam soundness, autoclave expansion, chemical analysis and 6 by 12-in. concrete cylinders made so that the cement was the only variable.

---

[1] Chief, Materials Testing Laboratory, Ministry of Public Works of Venezuela, Caracas, Venezuela.

One of the brands of cement contained from 5.5 to 9.6 per cent of MgO, and 90 samples of this cement, representing 350,000 sacks, were tested in order to determine the relationship between the MgO content and the expansion in the autoclave.

Samples:

All samples of cement consisted of unopened bags or barrels. The samples were, in most cases, taken from deliveries, and all imported cement was sampled as soon as it arrived in Venezuela.

Test Methods:

The normal consistency, time of set, fineness, and steam soundness tests, and the briquets were made in accordance with the A.S.T.M. Standard Methods of Sampling and Physical Testing of Portland Cement (C 77 - 32),[2] with the exception that the temperature of the mixing water, the moist room, and the water in the briquet storage tank were maintained at 25 ± 2 C. Twelve briquets were made for each cement, 6 for 7-day and 6 for 28-day test. The autoclave expansion test was made in accordance with the recommendations of A.S.T.M. Tentative Method of Test for Autoclave Expansion of Portland Cement (C 151 - 40 T),[3] with the exception that the bars remained in the autoclave for 5 min. after the cylinder had been opened. The chemical analysis methods were the same as A.S.T.M. Standard Methods of Chemical Analysis of Portland Cement (C 114 - 39).[4] Six 6 by 12-in. concrete cylinders were made for each cement, and 3 of these were tested at 7 days and 3 at 28 days. All of the mixes for the cylinders contained the same weights of cement, sand, coarse aggregate, and water. The water cement ratio for the cylinders was 0.69 by weight and the cylinders were cured in a moist room at a temperature of 25 ± 2 C. The sand for the mixes was all of the same quality and of exactly the same grading; the coarse agregate was the same quality of broken stone, separated into three sizes, and each size weighed out separately for each mix. Both the fine and the coarse aggregates were air dried in the laboratory for at least 3 months before being used.

Test Data:

The results of the comparative test of the 52 brands of portland cement are presented in Table I. A summary of the test results in Table I is presented in Table II. The test results for 90 samples of high MgO-content portland cement are presented in Table III. The relation between the tensile strength of 7- and 28-day briquets and the compressive strength of 7- and 28-day concrete cylinders with constant water-cement ratio is plotted in Fig. 1, and the variation in the 7- and 28-day compressive strength of constant water-cement ratio cylinders is plotted in Fig. 2.

DISCUSSION OF DATA

Time of Set.—All of the 52 brands of portland cement tested had an initial set in more than 45 min. and a final set in less than 10 hr.

Steam Soundness.—The results of the steam soundness test indicated that all of these cements were sound. We have made the steam soundness test on several thousand samples of portland cement and have never had a soundness pat fail this test even when the cement was known to contain an injurious amount of free lime.

---

[2] 1932 Supplement to Book of A.S.T.M. Standards, p. 23.

[3] 1940 Supplement to Book of A.S.T.M. Standards, Part II, p. 176.

[4] 1939 Book of A.S.T.M. Standards, Part II, p. 8.

TABLE I.—RESULTS OF COMPARATIVE TESTS OF 52 BRANDS OF PORTLAND CEMENT FROM 15 COUNTRIES.

Cement	Fineness, per cent retained on a No. 200 seive	Normal consistency, per cent of water	Tensile Strength-Standard Mortar Briquets, psi.		Compressive Strength-6 by 12-in. Concrete Cylinders, psi.		Autoclave Expansion, per cent	Oxide Analysis, per cent							
			7 Days	28 Days	7 Days	28 Days		Magnesium Oxide (MgO)	Calcium Oxide (CaO)	Silicon Dioxide (SiO_2)	Aluminum Oxide (Al_2O_3)	Ferric Oxide (Fe_2O_3)	Sulfur Trioxide (SO_3)	Insoluble Residue	Loss on Ignition
No. 1	14.2	22.0	302	372	1840	2900	0.05	1.56	66.0	21.5	4.34	3.29	1.16	0.11	2.51
No. 2	13.4	24.0	267	347	1565	2175	0.20	1.91	63.1	20.5	5.45	3.89	1.75	0.11	3.40
No. 3	20.2	21.2	326	398	1965	2790	0.15	3.08	63.4	20.1	7.05	2.87	1.21	0.46	1.24
No. 4	13.8	22.6	316	404	1920	2820	0.11	1.85	63.6	22.3	5.40	3.29	1.44	0.60	2.17
No. 5	16.0	23.2	327	421	2255	2900	0.32	0.88	64.2	21.5	6.13	2.62	1.53	0.68	2.35
No. 6	8.2	23.8	322	409	1795	2680	0.18	2.25	62.8	22.9	6.06	2.67	1.29	0.62	1.75
No. 7	20.0	21.0	274	393	1975	2920	0.05	2.64	64.5	23.1	4.54	2.24	1.31	0.61	1.04
No. 8	16.4	23.8	298	395	2000	2555	0.23	1.06	65.1	21.6	5.56	3.07	1.20	0.40	2.40
No. 9	15.0	23.0	299	366	1630	2450	0.04	1.53	63.9	22.1	4.77	4.00	1.48	0.60	1.47
No. 10....	15.2	22.8	273	395	1295	2290	0.12	0.88	63.7	23.8	5.44	2.42	1.40	0.30	1.94
No. 11....	17.6	23.4	233	319	1410	2350	0.36	1.51	63.0	21.6	6.40	2.46	1.44	0.15	3.67
No. 12....	15.2	24.0	353	406	2000	2905	0.25	1.56	64.1	20.2	6.78	2.23	1.92	0.22	3.41
No. 13....	17.0	24.2	350	400	2270	2930	0.26	1.90	62.5	19.2	7.91	2.95	1.77	0.29	3.48
No. 14....	15.6	23.5	334	384	1875	2950	0.33	1.64	64.2	20.4	6.10	2.99	1.61	0.30	2.98
No. 15....	21.0	21.4	302	315	1775	2390	0.26	2.33	61.8	19.5	5.70	3.28	2.05	0.42	4.68
No. 16....	18.0	21.4	340	409	1670	2495	0.07	1.39	62.5	22.7	6.29	2.43	1.23	0.66	2.10
No. 17....	12.4	24.4	338	378	2155	2670	0.22	1.92	62.0	22.0	7.10	2.37	1.77	0.65	1.57
No. 18....	14.4	22.8	290	404	1630	2335	0.29	2.45	61.5	23.1	6.60	2.16	1.67	0.55	1.94
No. 19....	15.8	22.8	331	382	2135	2920	0.01	1.67	64.0	21.5	6.70	2.53	1.51	0.35	1.43
No. 20....	15.4	25.0	326	399	1840	2470	0.27	1.42	63.8	20.4	7.34	2.11	1.71	0.20	3.61
No. 21....	14.4	25.2	357	404	2300	2965	0.22	1.59	65.0	21.5	5.99	2.10	1.78	0.36	1.83
No. 22....	10.0	23.8	349	454	2020	2975	0.04	2.50	63.1	23.0	4.05	2.62	1.54	0.37	2.30
No. 23....	9.6	22.8	355	374	2020	2525	0.67	1.17	64.3	20.0	6.17	2.05	2.16	0.60	3.75
No. 24....	12.2	24.5	409	453	2480	3150	0.12	2.29	62.1	19.1	7.41	2.55	1.71	0.16	4.85
No. 25....	12.0	24.4	402	446	2655	3300	0.11	2.39	64.0	19.4	7.18	2.70	1.47	0.20	3.15
No. 26....	12.2	24.8	383	414	3045	3640	0.14	2.62	63.1	19.8	6.13	2.74	1.75	0.28	4.00
No. 27....	8.2	26.8	351	442	2020	2970	0.05	2.24	53.9	20.6	9.23	2.58	3.82	0.44	6.88
No. 28....	5.6	24.0	290	385	1700	2565	0.34	2.01	62.3	21.1	6.72	2.85	1.27	0.30	3.00
No. 29....	8.2	25.0	356	398	2600	3225	0.15	1.92	63.7	19.5	5.74	3.08	1.27	0.44	4.01
No. 30....	12.4	24.0	417	466	2575	3195	0.15	2.01	63.9	20.4	6.48	2.70	1.62	0.29	1.80
No. 31....	15.4	23.4	358	431	2390	3085	0.11	1.90	64.2	20.4	6.44	2.74	1.71	0.50	1.83
No. 32....	9.8	23.2	343	434	2490	3565	0.30	4.23	62.1	20.1	6.70	2.38	1.76	0.37	2.87
No. 33....	3.8	22.6	362	437	2125	3250	0.00	2.38	64.3	20.8	5.85	3.89	1.51	0.44	0.67
No. 34....	4.0	25.5	411	472	3045	3550	0.04	1.44	66.4	21.8	4.98	2.12	1.21	0.56	1.52
No. 35....	12.0	22.4	357	434	2100	3170	0.09	1.22	65.3	23.4	5.52	1.47	1.61	0.28	1.40
No. 36....	11.0	24.4	351	438	2105	3055	0.16	1.39	63.4	20.0	6.64	3.45	1.86	0.24	3.30
No. 37....	16.2	23.0	348	390	2915	3585	0.06	1.75	64.3	22.1	5.02	2.26	1.76	0.44	2.98
No. 38....	11.2	24.5	365	436	2495	3470	0.02	2.92	64.0	18.6	7.11	3.04	1.99	0.56	1.00
No. 39....	11.6	23.6	363	407	2485	3185	0.22	2.00	66.5	21.9	4.87	2.16	1.35	0.44	1.42
No. 40....	11.0	24.0	259	369	1320	2050	0.01	1.33	61.3	22.3	5.75	3.96	1.39	0.30	3.57
No. 41....	14.6	23.0	281	397	1180	1985	0.03	1.14	62.2	22.6	5.68	3.67	1.16	0.51	3.10
No. 42....	11.8	23.2	358	388	2205	2985	0.20	1.21	63.3	22.0	6.10	2.94	1.28	0.40	2.39
No. 43....	18.4	22.0	308	421	1690	2465	0.09	1.41	63.7	22.4	6.39	2.52	1.50	0.46	1.45
No. 44....	16.6	22.0	328	423	2025	2725	0.06	2.63	62.6	21.4	5.66	3.10	1.94	0.46	1.52
No. 45....	11.8	23.6	307	364	1875	2595	0.20	2.02	62.3	21.3	6.85	2.70	1.71	0.42	2.00
No. 46....	12.4	24.2	362	368	2245	2685	0.42	1.90	62.8	19.8	8.25	2.67	2.43	0.67	1.59
No. 47....	14.0	22.8	401	428	2875	3405	0.08	1.37	65.6	20.9	6.22	2.26	1.74	0.50	1.03
No. 48....	19.0	21.4	250	355	1655	2675	1.36	6.82	56.8	18.9	7.26	5.76	1.57	0.26	2.36
No. 49....	14.8	23.4	315	408	1720	2495	0.76	3.04	62.5	20.0	6.92	2.24	1.62	0.36	2.71
No. 50....	11.8	21.8	395	465			0.15	1.26	63.8	19.9	6.40	3.20	1.92	0.54	2.42
No. 51....	15.6	23.0	380	470			0.40	1.30	63.3	19.7	7.70	2.70	2.21	0.64	2.55
No. 52....	13.4	24.6	290	375			0.11	1.44	62.6	22.8	4.75	2.49	2.20	0.32	3.50

Free Lime.—The chemical determination of free lime was not made for any of the cements since there does not appear to be a reliable method of determining the free lime content. Our experience has been that the free lime in a cement is rapidly converted by the action of the air into a form which does not cause expansion in the autoclave. One of the Venezuelan cement mills, because of the war and the failure of imported cement to be delivered in sufficient quantities to supply the demand, was forced to bag its cement directly as it came from the ball mill. This cement was immediately loaded onto trucks and delivered hot to the construction jobs. Over a period of several days our tests showed that the autoclave expansion of this cement was 7.5 per cent provided the autoclave bars were made as soon as the cement had cooled to room temperature. If, however, the sack of cement was dumped into a concrete mixing pan and turned over with a trowel, the autoclave bars made after the cement had been exposed to the air for 1 day had an expansion of 0.60 per cent. If the cement was again turned over with a trowel and autoclave bars made after the cement was exposed to the air for 2 days, the expansion dropped to 0.30 per cent, which was normal for this cement. On examining some hooped concrete columns which were poured with concrete containing this high free lime cement, it was found that the concrete had cracked around the outside of the top hoop, indicating that the hoops and the vertical reinforcing had restrained the concrete in the interior of the column from expanding as much as the outer concrete had expanded.

TABLE II.—SUMMARY OF THE RESULTS OF TESTS OF 52 BRANDS OF PORTLAND CEMENT COMPRISING TABLE I.

	Fineness, per cent retained on No. 200 Sieve.	Normal Consistency, per cent of Water.	Tensile Strength—Standard Mortar Briquets, psi.		Compressive Strength—6 by 12-in. Concrete Cylinders, psi.		Autoclave Expansion, per cent	Oxide Analysis, per cent							
			7 Days	28 days	7 Days	28 Days		MgO	CaO	SiO$_2$	Al$_2$O$_3$	Fe$_2$O$_3$	SO$_3$	Insoluble Residue	Loss on Ignition
Average	13.5	23.4	334	405	2068	2845	0.20	1.97	63.2	21.1	6.23	2.80	1.66	0.41	2.54
Minimum	3.8	21.0	233	315	1180	1985	0.00	0.88	53.9	18.6	4.05	1.47	1.16	0.11	0.67
Maximum	21.0	26.8	417	472	3045	3640	1.36	6.82	66.5	23.8	9.23	5.76	3.82	0.68	6.88

It appears reasonable to assume that with normal silo storage of portland cement, the small percentages of free CaO normally in a cement will react with the air used for conveying purposes and be converted to a form which will not cause expansion in the autoclave. A. H. Bogue has found[5] that the unsoundness due to free CaO can be differentiated from the unsoundness due to MgO by autoclaving one bar at 177 C. and steaming a second bar for 5 hr. at 100 C.

Autoclave Expansion Test.—In the autoclave expansion test only 2 of the 52 cements had an expansion of more than 0.50 per cent. These two cements were brands Nos. 23 and 48. Brand No. 23 had an expansion of 0.67 per cent and an MgO content of 1.17 per cent. Brand No. 48 had an expansion of 1.36 per cent and an MgO content of 6.82 per cent. The average autoclave expansion for the 52 brands of cement was 0.20 per cent with a minimum of 0.00 per cent.

7- and 28-Day Briquets.—The 7-day briquets for four of the brands of cement had a tensile strength of less than 275 psi. These were brands Nos. 2, 11, 40, and 48. At 28 days all but 3 of the cements had a tensile strength of more than 350 psi. These were brands Nos. 2, 11, and 15.

Magnesium Oxide (MgO) Content.—Only one of the brands of cement contained more than 5 per cent MgO. This was brand No. 48 which contained 6.82 per cent. It is interesting to note that the national specification for portland cement of the country from which this cement came limits the MgO content to a maximum of 5.0 per cent. A detailed investigation of this cement is presented in Table III.

Loss on the Ignition.—Sixteen of the

---

[5] A. H. Bogue, Paper No. 38 of the Portland Cement Association Fellowship, National Bureau of Standards, 1938, p. 30.

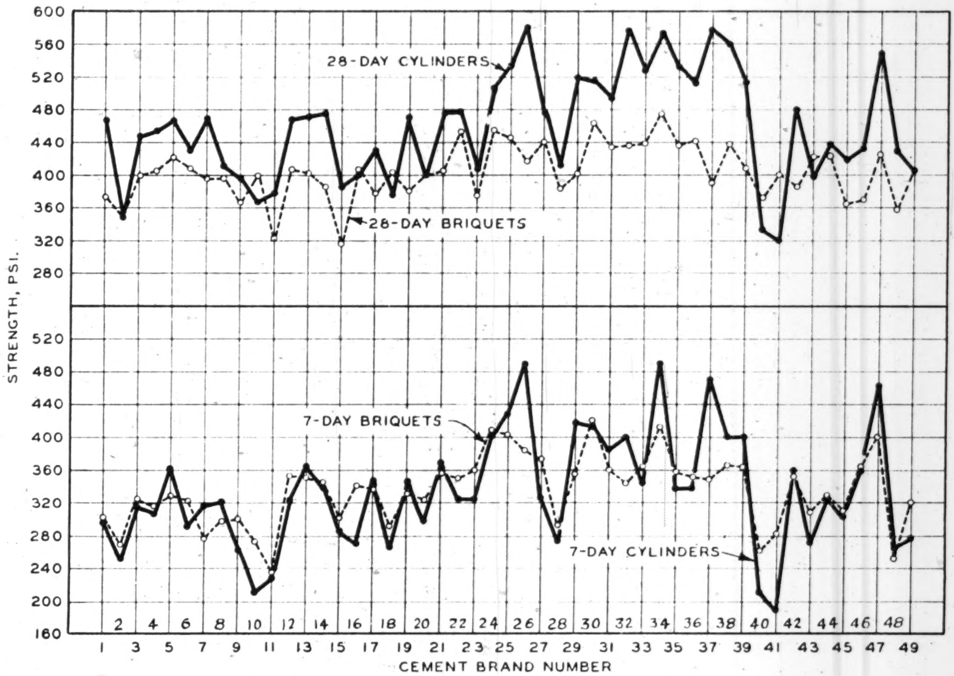


FIG. 1.—Relation Between the 7- and 28-day Tensile Strength of Briquets and the 7- and 28-day Compressive Strength of the Concrete Cylinders—all Cylinders Strengths Divided by 6.219 for Comparative Purposes.

$$\left(\frac{\text{average cylinder strength at 7 days}}{\text{average briquet strength at 7 days}} = 6.219\right)$$

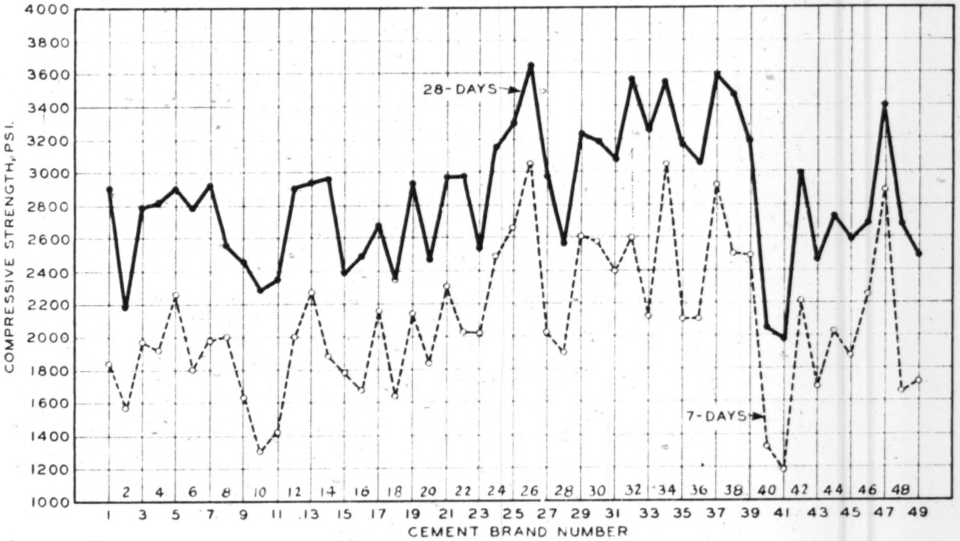


FIG. 2.—Results of 7- and 28-day Tests of Concrete Cylinders, all of which were made with the same Materials, Proportions and Water-Cement Ratio—Only variable; the Brand of Cement.

TABLE III.—COMPARATIVE TESTS OF 90 SAMPLES OF HIGH MgO CONTENT CEMENT REPRESENTING 350,000 SACKS OF EUROPEAN CEMENT (BRAND NO. 48).

Sample	Fineness, per cent Retained on No. 200 sieve	Normal Consistency, per cent of water	Briquet Strength, psi.		Autoclave Expansion, per cent	Oxide Analysis, per cent							
			7 days	28 days		MgO	CaO	SiO_2	Al_2O_3	Fe_2O_3	SO_3	Insoluble Residue	Loss on Ignition
No. 1	25.6	22.8	166	277	Disintegrated	7.14	57.40	18.30	7.16	6.00	1.80	0.50	1.86
No. 2	23.0	22.0	167	303	3.94	6.80	56.90	18.42	7.12	6.00	1.78	0.54	1.52
No. 3	23.2	23.0	181	274	6.08	6.63	57.20	18.30	7.48	6.76	1.71	0.52	1.52
No. 4	22.0	23.0	189	293	5.58	6.32	57.20	18.64	7.52	5.86	1.76	0.50	1.40
No. 5	17.0	22.8	215	321	Disintegrated	7.75	55.90	18.90	7.51	5.81	1.91	0.65	1.56
No. 6	14.6	23.6	223	327	Disintegrated	8.21	55.50	18.64	7.31	5.95	1.72	0.43	1.71
No. 7	14.6	23.6	218	311	Disintegrated	7.02	57.40	18.74	7.26	6.50	1.62	0.76	1.70
No. 8	14.8	23.0	201	290	Disintegrated	7.46	55.80	18.52	7.35	5.97	1.84	0.50	1.67
No. 9	18.2	22.6	245	337	Disintegrated	6.45	56.60	18.66	7.56	5.86	1.78	0.72	1.54
No. 10	23.8	20.4	226	287	1.54	6.51	56.00	18.46	7.45	5.55	1.80	0.30	3.27
No. 11	20.6	22.2	206	307	Disintegrated	6.93	55.60	18.72	8.78	6.02	1.83	0.69	1.58
No. 12	21.6	22.4	233	306	0.61	5.78	57.00	18.62	7.57	5.55	1.72	0.29	2.85
No. 13	15.8	22.8	190	300	Disintegrated	7.60	56.10	18.36	7.62	5.90	1.75	0.37	1.65
No. 14	21.0	21.2	233	318	0.92	6.25	56.30	18.64	7.40	5.48	1.75	0.31	2.96
No. 15	22.2	22.0	176	298	Disintegrated	8.42	55.40	18.58	7.20	5.98	1.46	0.70	1.45
No. 16	22.0	22.4	248	293	Disintegrated	7.38	56.80	18.40	7.35	5.83	1.53	0.81	1.61
No. 17	16.8	22.8	188	303	Disintegrated	6.85	57.00	18.56	6.72	5.94	1.54	0.67	1.61
No. 18	21.0	21.8	243	334	0.43	6.63	57.20	18.72	6.14	5.68	1.90	0.40	2.60
No. 19	19.0	22.2	193	319	Disintegrated	6.92	56.60	18.62	7.04	5.90	1.71	0.59	1.64
No. 20	19.0	22.6	190	302	Disintegrated	7.62	56.40	18.64	6.81	6.03	1.64	0.58	1.59
No. 21	16.2	23.0	183	260	Disintegrated	6.89	57.10	18.76	7.10	5.90	1.77	0.55	1.28
No. 22	22.6	21.0	247	325	0.74	6.10	57.20	18.58	7.34	5.72	1.74	0.30	2.67
No. 23	19.4	22.8	162	271	5.51	7.13	56.60	18.84	7.96	5.94	1.50	0.54	1.38
No. 24	18.0	23.4	211	309	1.81	5.49	57.20	18.82	7.38	5.82	1.89	0.48	1.42
No. 25	15.6	23.4	234	315	Disintegrated	6.55	56.60	19.12	7.00	5.86	1.95	0.40	1.57
No. 26	23.2	22.0	233	319	0.47	6.93	56.80	18.60	7.52	5.68	1.82	0.18	2.54
No. 27	19.4	21.8	217	303	Disintegrated	8.57	55.60	18.78	7.40	6.02	1.72	0.42	2.08
No. 28	16.6	22.6	216	326	Disintegrated	8.28	55.20	18.84	6.64	5.82	1.99	0.51	2.00
No. 29	21.0	21.4	220	297	4.13	7.85	55.80	18.58	7.48	5.86	1.78	0.51	2.47
No. 30	19.6	22.8	228	305	Disintegrated	8.77	55.20	19.32	7.14	4.80	1.85	0.74	2.00
No. 31	22.2	21.4	182	275	Disintegrated	9.63	53.80	19.08	6.80	6.02	1.76	1.00	2.14
No. 32	21.4	22.6	202	323	5.46	7.70	56.50	18.60	7.10	5.86	1.86	0.55	2.07
No. 33	20.4	21.2	254	337	1.31	5.82	57.10	18.54	7.56	5.50	1.84	0.62	2.52
No. 34	20.0	21.2	257	371	0.83	5.72	56.70	18.82	7.29	5.75	1.77	0.93	2.28
No. 35	19.2	21.4	259	344	0.82	5.80	56.70	19.04	7.60	5.60	1.78	0.52	2.47
No. 36	22.2	21.6	266	339	0.90	6.00	57.60	18.70	6.80	5.70	1.71	0.43	2.69
No. 37	23.0	21.6	267	351	0.76	5.63	57.20	18.86	7.27	5.75	1.44	0.39	2.82
No. 38	30.0	21.6	239	316	1.34	6.42	57.40	18.80	6.75	5.65	1.62	0.46	2.72
No. 39	25.2	21.6	280	352	1.57	6.22	57.20	18.90	6.95	5.55	1.83	0.50	2.98
No. 40	19.8	21.4	265	327	0.61	5.66	56.50	18.60	7.20	5.60	1.73	0.43	3.87
No. 41	23.0	21.6	264	334	0.69	5.65	56.00	19.06	7.87	5.65	1.91	0.61	3.52
No. 42	23.2	21.6	250	338	0.58	5.72	56.70	18.60	7.69	5.75	1.75	0.58	3.15
No. 43	14.8	22.6	200	297	4.12	7.00	55.80	18.86	7.62	5.70	1.69	0.71	3.03
No. 44	21.8	22.2	157	264	Disintegrated	9.55	53.70	18.18	7.87	5.55	1.78	0.90	2.79
No. 45	18.8	23.2	215	285	Disintegrated	7.23	56.80	18.26	7.66	5.60	1.67	0.63	3.04
No. 46	17.4	22.6	188	265	Disintegrated	7.27	56.70	18.26	6.76	6.20	1.63	0.46	2.87
No. 47	20.6	22.8	192	294	Disintegrated	8.62	54.40	18.56	7.55	5.55	1.71	0.50	3.16
No. 48	19.4	23.0	221	305	Disintegrated	7.57	55.20	18.96	7.51	5.65	1.87	0.63	2.66
No. 49	22.8	22.4	211	307	4.65	7.05	56.80	18.76	7.45	5.95	1.72	0.43	2.80
No. 50	17.0	23.0	234	336	5.55	7.73	55.50	18.20	7.36	6.00	1.83	0.53	2.97
No. 51	21.2	22.8	230	312	4.26	7.43	56.50	18.24	7.09	5.85	1.88	0.52	2.96
No. 52	21.0	22.8	215	278	4.62	7.71	55.00	18.14	7.20	5.95	1.77	0.47	3.24
No. 53	15.8	22.6	195	301	Disintegrated	8.22	55.90	18.20	7.07	6.05	1.74	0.60	2.93
No. 54	19.4	23.0	153	266	4.81	7.27	56.50	18.34	6.46	6.00	1.95	0.47	2.78
No. 55	15.4	22.4	231	323	5.06	7.57	57.10	18.44	7.21	5.55	2.11	0.47	2.50
No. 56	15.4	22.8	253	367	2.35	6.93	56.80	18.14	6.47	5.95	2.25	0.50	2.86
No. 57	22.6	22.6	189	306	5.30	7.90	56.50	18.28	7.21	5.45	1.91	0.47	2.94
No. 58	18.8	22.8	169	301	9.47	8.73	55.20	18.34	7.14	5.90	1.83	0.43	3.12
No. 59	21.4	22.4	173	306	2.02	7.28	56.60	18.60	6.35	6.05	1.59	0.39	3.02
No. 60	21.2	21.6	167	281	Disintegrated	9.55	53.30	18.49	7.37	6.10	1.81	0.42	2.35
No. 61	18.8	21.6	214	297	1.22	7.28	56.40	18.86	7.34	6.00	1.86	0.32	2.48
No. 62	14.0	21.6	202	302	1.39	6.83	56.30	18.76	7.21	6.05	1.51	0.43	2.72
No. 63	20.6	21.8	231	303	2.43	7.30	56.00	18.44	6.85	5.85	1.74	0.55	2.46
No. 64	21.8	22.0	169	255	Disintegrated	9.25	54.60	18.34	6.90	6.00	1.54	0.39	2.60
No. 65	20.0	21.6	200	305	1.40	7.41	55.70	18.24	7.61	5.95	1.54	0.35	2.31
No. 66	22.0	22.0	216	325	4.09	7.70	55.30	18.58	7.18	6.00	1.84	0.34	2.59
No. 67	20.6	22.0	178	285	Disintegrated	9.15	54.60	18.70	6.82	6.00	1.79	0.48	2.13
No. 68	19.2	22.0	244	361	2.82	7.42	56.50	18.42	7.21	5.65	2.06	0.64	2.42
No. 69	21.2	22.0	213	312	0.73	6.38	56.90	18.70	7.29	5.85	1.71	0.60	2.31
No. 70	22.2	21.6	253	348	5.42	7.30	56.60	18.66	7.00	5.70	1.96	0.86	2.42
No. 71	20.4	21.4	185	290	Disintegrated	9.07	54.60	18.56	7.23	5.95	1.57	0.46	2.68
No. 72	20.0	21.6	246	356	2.44	6.98	56.60	18.60	6.65	5.75	1.92	0.60	2.15
No. 73	18.8	21.4	231	370	1.41	6.93	56.70	18.54	7.18	5.70	0.71	0.74	2.67
No. 74	18.0	21.4	213	326	0.97	6.75	56.70	18.74	7.26	5.60	1.34	0.42	2.33

TABLE III—*Continued*

Sample	Fineness, per cent Retained on No. 200 sieve	Normal Consistency, per cent of water	Briquet Strength, psi.		Autoclave Expansion, per cent	Oxide Analysis, per cent							
			7 days	28 days		MgO	CaO	SiO_2	Al_2O_3	Fe_2O_3	SO_3	Insoluble Residue	Loss on Ignition
No. 75	22.0	21.2	213	312	1.55	6.65	57.00	18.46	7.26	5.50	1.12	0.57	2.54
No. 76	21.8	21.6	253	319	2.30	6.55	56.30	18.84	7.10	5.60	1.84	0.33	2.78
No. 77	21.6	21.4	242	334	2.70	6.63	56.80	19.02	6.89	5.65	1.74	0.62	2.27
No. 78	20.0	21.6	240	312	Disintegrated	7.43	56.70	18.34	7.13	5.75	1.82	0.54	2.82
No. 79	27.8	21.4	240	345	0.50	5.58	57.20	18.86	7.12	5.80	1.69	0.63	2.43
No. 80	21.0	20.6	229	299	Disintegrated	7.00	56.40	18.62	7.29	5.65	1.61	0.48	2.97
No. 81	24.4	21.0	220	290	1.89	6.73	56.00	18.62	7.23	5.55	1.73	0.47	3.11
No. 82	22.8	20.6	220	288	1.48	6.85	57.20	18.40	7.36	5.60	1.73	0.50	2.52
No. 83	21.8	21.4	213	315	0.75	5.70	56.70	19.06	7.42	5.60	1.49	0.62	2.51
No. 84	21.2	22.4	229	319	0.48	5.58	56.90	18.52	7.41	5.65	1.78	0.69	3.04
No. 85	27.8	21.8	216	323	0.68	5.52	57.00	18.92	7.04	5.60	1.33	0.33	3.51
No. 86	19.2	21.4	235	304	6.80	6.62	56.70	18.64	6.93	5.65	1.71	0.57	2.38
No. 87	25.4	21.2	244	317	0.73	6.03	56.80	18.98	7.11	5.55	1.61	0.35	2.80
No. 88	20.6	21.8	255	337	1.30	6.93	56.60	18.58	7.01	5.67	2.10	0.30	3.02
No. 89	19.0	21.4	249	354	1.36	6.82	56.80	18.92	7.26	5.76	1.57	0.26	2.36
No. 90	19.6	21.4	284	363	7.44	7.43	56.20	18.02	6.93	5.65	2.03	0.79	3.22

brands of cement had a loss on ignition of more than 3 per cent. These were brands Nos. 2, 11, 12, 13, 15, 20, 23, 24, 25, 26, 27, 29, 36, 40, 41, and 52. The loss on ignition was determined in a muffle furnace at 1000 C.

SO_3 Content.—Five of the cements had an SO_3 content greater than 2.0 per cent. These were brands Nos. 15, 27, 46, 51, and 52.

Insoluble Residue.—All of the cements had an insoluble residue of less than 0.75 per cent.

Table II contains a summary of the data presented in Table I. Comparison may be made with the findings of A.S.T.M. The A.S.T.M. Committee C 1 on Cement studied 32 brands of portland cement, so selected as to cover the United States products. The report of this study is summarized in the 1928 *Proceedings*.[6]

In Fig. 1 the 7- and 28-day briquet strengths have been plotted against the 7- and 28-day concrete cylinder compressive strengths. For comparative purposes, all concrete cylinder strengths were divided by 6.219, which was the factor obtained by dividing the average cylinder strength at 7 days by the corresponding average briquet strength at 7 days. A study of Fig. 1 indicates that the briquet strength at 7 days usually bears some relation to the cylinder strength. However, even at 7 days the discrepancies are so frequent and of such magnitude that the 7-day tensile strength cannot be considered to be a reliable index of cylinder strength. At 28 days the briquet strength does not appear to bear any relation to the cylinder strength. In view of the test results plotted in Fig. I, it is surprising that the briquet test has continued for so many years as one of the major tests to determine the quality of a cement.

In Fig. 2 the 7- and 28-day concrete cylinder strengths have been plotted. The 7-day strengths varied from a low of 1180 psi. for brand No. 41 to a high of 3045 psi. for brands Nos. 26 and 34. Hence, at 7 days cements Nos. 26 and 34 had 268 per cent of the strength of cement No. 41. At 28 days the strength varied from a low of 1985 psi. for brand No. 41 to a high of 3640 psi. for brand

---

[6] Report of Sub-Committee VII on Strength: Report on "Cooperative Tests of Thirty-Two Portland Cements by Forty-Seven Laboratories," *Proceedings*, Am. Soc. Testing Mats., Vol. 28, Part I, p. 261 (1928).

No. 26. Thus, cement No. 26 had 183 per cent of the strength of cement No. 41 at 28 days. Although the percentage difference appears to decrease rapidly from 7 to 28 days, it will be seen that the actual difference in pounds per square inch does not change very much. The actual difference at 7 days is 1865 psi. and at 28 days it is 1655 psi. It will be seen from Fig. 2 that 4 of the cements, brands Nos. 26, 32, 34, and 37, have outstanding 28-day cylinder strengths. Figure 2 emphasizes the fact that there may be an extremely great difference in quality between different portland cements that comply with ordinary specification requirements.

In Table III are presented the results of comparative tests of 90 samples of high MgO content cement representing 350,000 sacks of European cement all of brand No. 48. The MgO content of these samples varied from 5.5 per cent to 9.6 per cent, and the autoclave expansions varied from 0.43 per cent to disintegration. The expansion in the autoclave does not appear to bear any direct relation to the MgO content although disintegration did not occur for any sample having less than 6.55 per cent of MgO. White and Kemp[7] demonstrated that MgO can combine with SiO_2 under the conditions of cement making. Bogue[5] states that MgO in the form of glass does not cause autoclave expansion and that if cement clinker is rapidly cooled, most of the MgO will be present in the form of glass. It would therefore seem reasonable to believe that the autoclave expansion does not bear any direct relation to the total MgO content, for the 90 samples of high MgO cement tested, because the sum of the combined MgO and the MgO present in the form of glass varies for each of the samples tested.

This high MgO-content cement (brand No. 48) was delivered to Venezuela but was rejected as a result of the laboratory tests. A part of this cement was used to construct a cement—soil stabilized base for the drill grounds and approach roads of an armory. The cement—soil mixture was closely controlled and compacted at optimum moisture, and contained 12 per cent of cement by volume. Control specimens were made up at the same time and placed in the moist room. One of the control specimens contained 8 per cent cement and the others 12 per cent cement by volume. The control specimens have now been in the moist room for 3 yr. and 3 months and the specimen containing 8 per cent of cement has started to disintegrate at the lower end where it is in contact with an asbestos cement sheet. Disintegration at this point is apparently due to the fact that a small amount of water is usually present on this sheet. The specimens containing 12 per cent cement do not show any signs of disintegrating.

The cement soil base was exposed to the weather for about 10 months after it was constructed and was then covered with a crushed stone-emulsified asphalt wearing course. To date no cracks have appeared in this wearing course.

A sample of this cement, that had been stored in a warehouse for 3 yr., was tested. The autoclave expansion was 8.1 per cent and the MgO 5.55 per cent. It therefore appears that the autoclave expansion of this cement has not been decreased by 3 yr. of storage in a warehouse in 4-ply paper bags.

CONCLUSIONS

1. The expansion in the autoclave test does not bear any direct relation to the total MgO content of the cement.

2. The tensile strength of briquets at 7 days usually bears some relation to the 7-day compressive strength of con-

---

[7] Alfred H. White and Harold S. Kemp, "Long-Time Volume Changes of Portland Cement Bars," *Proceedings*, Am. Soc. Testing Mats., Vol. 42, p. 727 (1942).

crete cylinders made with a constant water—cement ratio, but the discrepancies are so frequent and of such magnitude that the 7-day briquet strength cannot be considered a reliable index of cylinder strength.

3. The 28-day briquet strength does not appear to bear any relation to the 28-day concrete cylinder strength.

4. The 7-day compressive strength of constant water—cement ratio concrete cylinders made with the brands of cement tested varied from 1180 psi. to 3045 psi. and the 28-day strength varied from 1985 psi. to 3640 psi.

5. The water-cement ratio - strength relationship varied so widely for the brands of cement tested that an average water-cement ratio – strength curve would have very little value for designing concrete mixes with these brands of cement.

6. On the basis of the 7-day concrete cylinder strength the minimum increase in strength from 7 to 28 days was 16.6 per cent, the maximum 76.8, and the average 37.6.

7. The autoclave expansion of 0.50 per cent required by the A.S.T.M. Standard Specification for Portland Cement (C 150 – 42)[8] is a reasonable requirement.

8. Most of the 52 brands of portland cement tested complied with the A.S.T.M. Specifications that were effective at the time the cements were tested, and several countries produced excellent quality portland cement.

Acknowledgment:

This investigation was conducted in the Materials Testing Laboratory of the Ministry of Public Works in Caracas. The author is indebted to Amos Aleman and Enrique Stolk for their assistance in conducting the physical tests, to Jaime de Elguezabal and Paul Reynolds for conducting the chemical tests, and to Joseph Andara and Joseph Baldo for assistance in the preparation of tables and figures.

Acknowledgement is made to Francisco J. Sucre, Director of Ways of Communication of the Ministry of Public Works, for permission to publish the results of the investigation.

---

[8] 1942 Book of A.S.T.M. Standards, Part II, p. 1.

DISCUSSION

Mr. W. C. Hanna.[1]—Referring to Table III, of the paper, which shows a comparison of the magnesium oxide content, I notice that the SiO_2 content ranges around 18 per cent, while in the Society's Standard Specifications for Portland Cement,[1a] type II, it is required that the SiO_2 content be over 21 per cent. The Al_2O_3 content in most of the samples listed in Table III shows about 7 per cent, whereas in the standard specifications for type II cement, the requirement is less than 6. I believe that the results would have been entirely different had the SiO_2 content been kept above 21 per cent, the Al_2O_3 content below 6 per cent, and the MgO content as given. In other words the results reported were not caused by the high MgO but because of the lack of SiO_2 or an unfavorable composition.

Mr. M. A. Swayze.[2]—I think it is a fine thing to get some papers on portland cement from outside of this country. Robert Burns, you remember, said that it is a good thing to see ourselves as others see us.

It is too bad, perhaps, that only four cements were shown from the United States, as compared with a large number from other countries. I presume the reason for this is probably a matter of trade and price. The point that interested me, and on which the paper threw no light, was in the table of chemical analysis, and especially in the column giving the loss on ignition. The majority of the losses on ignition are relatively high for cements as we know them here. Practically all of those shipments, of course, were water shipments, and the statement is that they were in paper sacks or barrels. It would be of considerable interest and help to the manufacturers in this country if they could know what types of packages those various cements were shipped in, so that they could learn from that information how best to ship cement to protect it from sea voyages.

Mr. P. H. Bates.[3]—There is another item on which I wonder whether Mr. Barrett could give us a little more definite information than he has. What were the specifications under which these cements were purchased? Somehow, I gathered that they were the A.S.T.M. specifications, but it is not quite clear.

An item which is of considerable interest to Committee C-1 on Cement is the relatively low SO_3 contents of these cements from foreign countries, where they allow $2\frac{1}{2}$ per cent SO_3. If these foreign manufacturers were allowed to use their own specifications, it is surprising that they did not deliver a lot of 2-plus SO_3 cements.

Mr. Nicolaas T. F. Stadtfeld.[4]—The author is somewhat optimistic, I think, in suggesting, in his conclusion, that the compressive strength of a concrete cylinder is representative of stress development in a structure. It is perfectly all right for him to say that the tension test does not mean anything as far as these compression test cylinders are concerned. That is true, but the compression test cylinder also means very little as to allowable stresses in a structure.

---

[1] Chief Chemist and Chemical Engineer, California Portland Cement Co., Colton, Calif.

[1a] 1942 Book of A.S.T.M. Standards, Part II, p. 1.

[2] Director of Research, Lone Star Cement Corp., Hudson, N. Y.

[3] Chief, Clay and Silicate Products Div., National Bureau of Standards, Washington, D. C.

[4] Division Engineer, Board of Water Supply, New York, N. Y.

To elaborate: It is customary to speak of 4000 psi. concrete, meaning that in the testing of a 6 by 12-in. cylinder a compressive strength of 4000 psi. is obtained. Truly, the compressive strength is unknown. If we should thoroughly grease both ends of the cylinder before testing, this apparent strength, according to some authorities, would be reduced up to 35 per cent, but considering only my own tests run some years ago, a 20 per cent reduction is reasonable; in addition, inasmuch as the ends of the cylinder are no longer rigidly held, a true columnar break occurs indicating that the specimen breaks by tension rather than by tension and shear as in the standard test. Lack of proper curing will reduce the apparent strength another 10 per cent, and increasing the size of the cylinder will account for an additional 18 per cent reduction. These variations applied simultaneously leave us an apparent strength of only 2080 psi.

On the other hand, if we allow the cylinder to dry out thoroughly before testing, the apparent strength will increase 25 per cent, and with a smaller height with the same diameter another 10 per cent increase will appear. We now have brought the apparent cylinder strength up from 4000 psi to 5400 psi. Now take into consideration that in testing 3 cylinders made from the same batch of concrete, strengths may vary from 3600 to 4400 psi. No one knows whether the high or low value is the correct one, and it becomes apparent that what is commonly called 4000 psi concrete may either be 2000 psi or 6000 psi. concrete as far as the value of this figure is concerned for the designer of concrete structures.

It is for this reason that such a large safety factor is necessary in concrete design, as the idealized conditions in the compressive strength test of concrete cylinders never exist in the structure.

I wanted to bring out this point so that we do not get too optimistic and assume that in testing a concrete cylinder we know anything about what is going to happen to a structure except within very large limits.

MESSRS. S. P. WING[5] AND R. E. KENNEDY[5] (*presented in written form*).—The paper provides the basis for an interesting comparison between the variations in strength of portland cement from mills with a world-wide distribution and those from mills located in this country, a survey of which was published in 1928.[6] The paper's data show for tests on 6 by 12-in. cylinders, with a water-cement ratio of 0.69, mean strengths at 7 and 28 days of 2060 and 2840 psi., with coefficients of variation between brands of 21 and 14 per cent, respectively. The corresponding values in 1928, at a water-cement ratio of 0.60, were 1850 and 3120 psi., with coefficients of variation of 20 and 13 per cent. Allowing for the difference in water-cement ratio, in the intervening 10 years between the two surveys there is an apparent 20 per cent increase in the strength potentialities of the cement, presumably largely due to finer cement grinding now current. The variation between different brands, surprisingly enough, was no greater on a world-wide basis in 1938 than that found for this country in the earlier survey. Evidently cement manufacture has reached a high degree of standardization throughout the world.

The paper depreciates the use of the

---

[5] Engineer and Assistant Engineer, respectively, U. S. Bureau of Reclamation, Denver, Colo.

[6] Report of Subcommittee VII on Strength: Report on "Cooperative Tests of Thirty-two Portland Cements by Forty-seven Laboratories," *Proceedings*, Am. Soc. Testing Mats., Vol. 28, Part I, p. 261 (1928).

cement tension briquet test as a measure of the strength-producing properties of the cement, stating that at seven days "the discrepancies are so frequent and of such magnitude that the 7-day briquet strength cannot be considered a reliable index of cylinder strength" and "the 28-day briquet strength does not appear to bear any relation to the 28-day concrete cylinder strength."

Statistical analysis shows on the contrary that for both cases a highly significant correlation exists between the concrete strengths and the cement tests, the correlation coefficients being 0.84 and 0.61 for the two cases. Seventy and 31 per cent of the total 7-day and 28-day variance of the concrete cylinder strengths are accounted for by variations in the cement as recorded by the tension tests. The analysis indicates that for each 1-lb. change in the tensile strength of the cement, an 8.7 psi. and 7.5 psi. change may be expected in the 7- and 28-day strengths of the concrete cylinders, the variation remaining after these allowances being reduced to 11 per cent in both cases. When it is considered that the concrete cylinders were molded at constant water-cement ratio, and consequently at varying slump, whereas the tension cement tests were made at varying water-cement ratios but of equal consistencies, the unaccounted-for variation in the concrete cylinders not attributable to normal experimental error is to a considerable extent explained.

While the author's criticism of use of tension tests for determining the quality of cement is not considered justified on the basis of the data presented, the high predictive value of his 7-day, 6 by 12-in. concrete tests for determining 28-day strengths is noteworthy. With a coefficient of correlation of 0.92, the prediction equation for 52 brands of cement at a water-cement ratio of 0.69 is $Y = 1.38\bar{X} + 0.86(X - \bar{X})$ where Y is 28-day strength, $\bar{X}$ is the mean 7-day strength (2070 psi.), and X is the observed 7-day strengths of the 6 by 12-in. cylinders. From this equation, the author could predict his 28-day strengths for any brand of cement, with an error measured by a standard deviation of 5.5 per cent, a value within the limits of experimental error.

Finally it should be mentioned that the 14 per cent coefficient of variation between brands of portland cement, disclosed by these tests, is in reality a measure of variation between single *samples* of different brands. It is known that even samples from single brands vary widely, with coefficients of variation of perhaps 8 to 12 per cent. If the variance within a brand, in accord with this estimate, be subtracted from that measured by the author, a coefficient of variation of only 11 to 7 per cent between the output of different mills is indicated. This is truly a remarkable uniformity for a product produced under such diverse circumstances, in widely separated localities. At the same time it indicates that a consumer may well find it possible to buy a standard portland cement on the average market, with a 20 to 30 per cent excess 28-day strength-producing capacity, if he will but examine the average strength levels of the various brands offered.

MR. EUGENE V. BARRETT[7] (*author's closure, by letter*).—Mr. Hanna has refered to the fact that the SiO_2 contents in Table III range around 18 per cent and that in the Society's Standard Specifications for Portland Cement (C 150 – 42)[8] it is required that the SiO_2 content for type II cement be over 21 per cent. The actual range is from 18.02 to 19.32 per cent. This cement was received and tested prior to the adoption of the requirements for type II portland cement in 1941 (C 150 – 41), and the present specification for type I cement does not specify the SiO_2 content.

---

[7] Chief, Materials Testing Laboratory, Ministry of Public Works of Venezuela, Caracas, Venezuela.

[8] 1942 Book of A.S.T.M. Standards, Part II, p. 1.

Mr. Swayze has raised an interesting question relative to the type of packages in which the several brands of cement were shipped and the possible effect of the type of package on the loss on ignition. The bagged cement arrived in 42.5-kg. (94-lb.) and 50-kg. (110-lb.) paper bags. The bags were of three types—4-ply paper with none of the ply treated to make them more impervious—6-ply paper with none of the ply treated and 6-ply paper with one of the ply treated to make it more impervious than ordinary paper. Our experience was that the maximum breakage of bags in transit occurred with the 50-kg., 4-ply bags and that there was more breakage of 42.5-kg., 4 ply bags than of the same weight bag with 6 ply. We also found that the cements packaged in 6-ply bags with one impervious ply had low ignition losses and appeared to have less hardening in storage than the cements packaged in the other types of bags. As a result the Ministry of Public Works specification requires that cement be shipped in 6-ply, 42.5-kg. bags with one of the ply treated to make it more impervious than ordinary paper.

Mr. Bates has inquired as to the specifications under which these cements were bought. The specifications were equal in requirements to C 9 – 30.[9] The SO_3 content is usually below 2 per cent unless the fuel or the raw materials contain an excessive amount of sulfur. Even then it is possible to reduce the SO_3 by burning at a high temperature.

Mr. Stadtfeld's statement that it was suggested in the conclusions "that the compressive strength of a concrete cylinder is representative of stress development in a structure" is not based on fact and his remarks as to the value of concrete control by means of test cylinders are completely contrary to my experience.

Messrs. Wing and Kennedy have unquestionably devoted a great deal of study to this paper and their discussion is very interesting.

---

[9] 1930 Book of A.S.T.M. Standards, Part II, p. 25. The Standard Specifications C 9 have been discontinued and replaced by Specifications C 150.

A COMPARISON OF RESULTS OF SIEVING PROCEDURES IN SOUNDNESS TESTS ON MAINE SANDS

By Andrew Adams[1] and Horace A. Pratt[2]

Synopsis

A series of tests to investigate the effect of the magnesium sulfate soundness test on Maine sands indicates that the inclusion of an alternate procedure in the method may be unnecessary. These tests, made at the Maine Technology Experiment Station during the years 1942 and 1943, were performed by both procedures specified in the A.S.T.M. Tentative Method of Test for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate (C 88 - 41 T) on 64 sands from sources well distributed over the state. The apparent high correlation between the two procedures was verified by statistical methods. The results obtained on Maine sands by final sieving over the original sieves are equally as good as the results obtained by final sieving over the half-size sieves.

The increasing use of the magnesium sulfate soundness test to determine the suitability of concrete aggregates influenced the Maine Technology Experiment Station, Orono, Maine, to undertake, in 1942 and 1943, a series of tests to investigate the effect of the soundness test on Maine sands. These tests were made according to the A.S.T.M. Tentative Method C 88,[3] which provides two different procedures for determining the soundness results. In one, the sands which have been exposed to the sulfate solution are subsequently sieved over the original sieves, while in the alternate procedure,[4] they are sieved over half-size sieves.[5] Both procedures were used in these tests and the resulting data were analyzed by statistical methods to determine just how closely the results of the two test procedures, as applied to Maine sands, were related. This paper deals with the results of that study.

Derivation of Data

The 64 sands used in making these soundness tests came from 32 different sources well distributed geographically over the state of Maine, and varied mineralogically from wholly granitic (quartz and feldspar) sands to those containing large percentages of quartzite, schist, and shale. These sands did not contain any appreciable amount of limestone.

The following procedure was used in interpreting the A.S.T.M. Method C 88.

Since the result of the soundness test is weighted according to the grading of the sand, the first step in performing the test was to make a sieve analysis on a 1000-g. sample of each sand tested. Tyler sieves Nos. 4, 8, 14, 28, 48, and 100 were used in making this analysis.

After the fractions had been separated, as a result of making the sieve analysis, samples weighing 100 g. were taken from each of the four required sizes and placed in separate baskets preparatory to immersion in the magnesium sulfate solution. These baskets, about 3 in. square and 3 in. deep, had side walls of sheet copper and bottoms made from 100-mesh woven wire cloth.

---

[1] Senior Engineer, Bridge Division, Maine State Highway Commission, Augusta, Me.

[2] Assistant Engineer, Maine Technology Experiment Station, University of Maine, Orono, Me.

[3] 1942 Book of A.S.T.M. Standards, Part II, p. 1185.

[4] After considerable investigation, it was found that the basic work inthe use of the half-size sieves in this connection appears to have been done in the laboratories of the National Sand and Gravel Association, Washington, D. C.

[5] Sieves having square openings one half the width of the openings in the sieves originally used in separating the fractions.

The soundness test was run on 28 samples at a time, that is, samples of each of the four required sizes from each of seven different sands. The immersion tank was amply large to accommodate this number of samples, and was kept in a small room where the temperature was controlled within the required limits at all times.

The magnesium sulfate, a commercial grade of epsom salt, was made into a saturated solution in the immersion tank well in advance of placing the sand samples in it. Enough of the salt was used so that excess crystals were always present, and the specific gravity was maintained between 1.296 and 1.308. The solution was stirred twice daily, once immediately after the baskets were withdrawn from the immersion tank and again just before they were returned to it.

The samples were immersed in the magnesium sulfate solution for 16 hr., following which they were drained for 15 min., and then placed in a drying oven that was maintained at a temperature between 105 and 110 C. for 7 hr. The samples were then cooled for about 45 min. and again immersed in the solution. This procedure was repeated through five cycles, except that the length of the immersion period which came at the week-end was 64 hr.

After the completion of the fifth cycle, each sample was washed entirely free of the magnesium sulfate, dried, weighed, and sieved both over the sieve on which it was originally retained and over the next smaller (half-size) sieve. From the weights of the material retained on these sieves, the actual percentages of loss were calculated for each fraction and for both procedures. These several percentages of loss, for the four fractions used for each sand, were weighted according to the grading of the sand and combined to give the total weighted percentage loss for the entire sand.

ANALYSIS OF RESULTS

A comparison between the results of the two test procedures can be made from the data presented in Table I.

TABLE I.—AVERAGE WEIGHTED PERCENTAGE LOSS FOR 64 SANDS.

Sand Fraction (Tyler Sieves)	Average Weighted Loss, per cent		Ratio of Losses (Half-Size/Original)
	Original Sieves	Half-Sized Sieves	
No. 4 to No. 8	1.42	0.75	0.53
No. 8 to No. 14	2.00	1.12	0.56
No. 14 to No. 28	2.04	0.92	0.45
No. 28 to No. 48	1.41	0.57	0.40
Total	6.87	3.36	Average 0.49

The entries in this table are average results for the 64 sands tested, and the table shows the average weighted loss for each of the four required fractions and for both test procedures. The figures in the last column of the table show, for each fraction and for the total weighted loss, the ratio of the loss using half-size sieves to the loss using original sieves. These figures indicate that, in each case, the loss obtained by using the half-size sieves is about one half that resulting from the use of the original sieves.

In order to represent graphically the relationship between the results of the standard procedure and the alternate method, and to determine a statistical measure of this relationship, the data for the soundness tests on the 64 sands were plotted, resulting in the scatter diagram

	Weighted Percentage Loss on Original Sieves																					
Weighted Percentage Loss on Half-size Sieves	1.6	2.4	3.2	4.0	4.8	5.6	6.4	7.2	8.0	8.8	9.6	10.4	11.2	12.0	12.8	13.6	14.4	15.2	16.0	16.8	17.6	N
0.5	5	1	1		1																	8
1.0		1	3	1	1		1							(r = 0.9471 ± 0.0271)								7
1.5			1	3	2																	6
2.0					1	1	1															3
2.5					2		1		1													4
3.0					1	1	5	3														10
3.5					1	2	1	1		1	1											7
4.0							1	2	1			1										5
4.5								1	1	2	1											5
5.0									1	1												2
5.5										1	1											2
6.0													1									1
6.5																						
7.0																						
7.5																						
8.0														1								1
8.5																						
9.0																						
9.5																	1		1			2
10.0																						
10.5																					1	1
N	5	2	5	4	9	4	10	7	4	5	3	1	1	1			1		1		1	64

FIG. 1.—Scatter Diagram Showing Relationship Between Results Using Original Sieves and Results Using Half-Size Sieves.

shown as Fig. 1. The figures within the small squares in Fig. 1 represent the number of tests falling within the indicated ranges of the two variables. For instance, in the first square at the upper left corner of the diagram is the figure *5* which means that there were five tests in which the losses on the half-size sieves were between 0.5 and 1.0 per cent with corresponding losses on the original sieves between 1.6 and 2.4 per cent. It will be noted that these plotted points are arranged in very nearly a straight line diagonally downward across the diagram. The narrowness of this band of points indicates that the two variables are very closely related.

From this scatter diagram, a numerical measure of the relationship between the two variables was obtained by calculating the correlation coefficient, r, according to the method described by H. W. Leavitt.[6] As would be expected from the appearance of the scatter diagram, a very high correlation coefficient ($r = 0.9471 \pm 0.0271$) was obtained. The fact that this coefficient is positive indicates a direct relationship between the variables; that is, as the value of one variable increases, the value of the other also increases.

The close relationship between the two variables, as indicated both by the narrowness of the band of plotted points in the scatter diagram and by the magnitude of the correlation coefficient, shows that both procedures for obtaining the percentage loss caused by the action of magnesium sulfate on Maine sands are equally good. As far as results are concerned, they both tell the same story.

---

[6] H. W. Leavitt, "A Method of Evaluating Concrete Data by Correlation," ASTM BULLETIN, No. 91, March, 1938, p. 15; or Maine Technology Experiment Station, *Paper No. 22*, March, 1938.

CONCLUSIONS

The conclusions derived from this study of the results of sieving procedures in the magnesium sulfate soundness test on Maine sands may be summarized as follows:

1. The percentage loss in the soundness test on Maine sands using half-size sieves is about one half that obtained with the use of original sieves, both in the case of the separate fractions and for the weighted totals.

2. The coefficient of the correlation between the results of sieving over the original sieves and the results of sieving over the half-size sieves was $r = 0.9471 \pm 0.0271$, indicating a very high relationship between the two test procedures.

3. The high relationship between the two procedures indicates that both methods are equally satisfactory as applied to Maine sands.

4. Inasmuch as the A.S.T.M. Method C 88 indicates no preference for either procedure, unless results from some particular region indicate the necessity for having an alternate procedure, it is suggested that the alternate procedure may be superfluous and might well be eliminated.

APPLICATION OF FLY ASH FOR LEAN CONCRETE MIXES

BY HARRY A. FREDERICK[1]

SYNOPSIS

This paper demonstrates the use of fly ash as a partial substitute for sand and also for cement in lean concrete mixes (2 to 3 bags of cement per yard and water-cement ratio = 15 to 20 gal. per bag of cement).

Results of tests covering both methods of fly ash substitution are quite conclusive.

The accompanying data point out very clearly that there is a decided improvement in strength and workability when fly ash (dry, wet, or with high carbon content) is substituted for sand. As a result of this substitution less cement is required to secure a given strength. Substitution of fly ash for cement alone does not improve strength or workability in lean mixtures.

OBJECT OF TESTS

In the past decade much has been written regarding the fly ash disposal problem and the possible use of this waste product. The apparent consensus of opinion among the electric utility companies burning pulverized coal is that the establishment of a commercial use for fly ash will automatically eliminate the disposal problem.

Concurrent with this disposal problem facing the electric generation department, our construction department was faced with the improvement in the design of concrete used as a fill around underground electric cable duct line assemblies. The two are interrelated as described below.

The construction standards for our present duct line assemblies requires that the bank of fiber or transite tubes be encased in a concrete envelope approximately 3 in. thick. High strength is not required; extreme workability on the other hand is a most desirable factor.

Attempts to design a concrete mix using the conventional ingredients and meeting the above requirements (500 psi. and 6 in. slump) were very disappointing. Considerable bleeding of the mixing water and segregation of the aggregates resulted. The strength stipulation was met, but not the workability.

Analysis of this lean mix (2 to 3 bags of cement per cubic yard and water-cement ratio = 15 to 20 gal. per bag) showed a definite lack of paste content. The low paste content was due, of course, to the low cement factor which in turn was dictated by the strength stipulation.

Experiments conducted in our laboratories indicate that this deficiency in paste content can be corrected by substituting fly ash for a portion of the normal sand content in these lean mixtures. The optimum percentage of substitution will depend on the type and gradation of the aggregates used. Other fines such as limestone dust, stone quarry dust, fine sand, and silt have been used as a substitute for coarse concrete sand with results in no way approaching those obtained with fly ash. The fact that fly ash is approximately twice as fine as normal portland cement and has a greater percentage of fine material makes it a desirable ingredient for augmenting the paste content of lean mixes. These fly ash fines help take up excess water and produce added paste for lubricating the mix.

---

[1] Assistant Materials Division Chief, Maplewood Lab., Public Service Electric and Gas Co., Maplewood, N. J.

OUTLINE OF TESTS

In studying the lubricating and strength contributing qualities of fly ash, the tests were grouped into four series.

In the first series dry fly ash was used to replace varying percentages of sand. The substitutions were increased in increments of 5 per cent, by weight, of the sand content until the mix became unworkable.

In the second series dry fly ash was used to replace varying percentages of cement. Here again the substitutions were increased in increments of 5 per cent of the cement until the mix would not retain sufficient water for workability.

In the third series wet fly ash, 100 per cent saturation, was used in the same manner as in the first series.

The fourth series was intended to provide comparisons of plain and fly ash concrete mixtures of varying richness. In the fly ash batches in this group, dry fly ash was used to replace 25 per cent of the sand.

Materials:

A standard brand of portland cement was used in all mixes. The sand and gravel were of commercial concrete grade obtained from the Long Island Bay area. The gravel was $\frac{3}{4}$ in. in size. All aggregates were proportioned dry.

The fly ash was obtained at two collection points in our generating stations. The dry fly ash was obtained at the precipitators located in the boiler breaching near the smoke stack. The wet fly ash was obtained from a disposal pond into which the boiler dump and fly ash are sluiced.

Testing Procedure:

Twenty-eight batches of concrete (approximately 1/50-cu. yd. batches) were proportioned by weight and tested for slump, flow, and compressive strength. Three standard 6 by 12-in. test cylinders were made of the concrete in each batch. The cylinders were moist cured and tested in compression at 7, 28, and 90-days after casting.

The total moisture content of the wet fly ash used in series 3 was determined by the hot-plate method. The percentage of moisture thus determined was used in calculating the amount of wet fly ash and water for each batch.

In series 1 and 3 the water-cement ratio and coarse aggregate content were maintained constant for each batch. Fly ash was substituted in increasing amounts for an equivalent weight of sand to determine the optimum percentage of substitution as observed by the workability and strength tests.

In test series 2 the water-cement ratio was gradually increased. The quantity of sand, coarse aggregate, and total water were maintained constant for each batch.

In the plain and the fly ash batches in series 4 the cement content was varied and the percentage of fly ash substitution maintained constant.

RESULTS OF TESTS

Table I summarizes the results of the chemical and physical tests conducted on the samples of fly ash received.

The variation in the carbon content may be attributed to the type of coal burned. This variation had little effect on the strength as shown by the following comparison: The carbon content of sample No. 174 used in test series 4 (Table III) is more than double that of sample No. 85 used in series 1. Figure 2(*a*) shows the strength of the concrete containing 25 per cent of fly ash (sample No. 85) to be 1017 psi. at 7 days and 1662 psi. at 28 days. In Fig. 4 the strength of a comparable mix (2.64 bags of cement per cu. yd. and 25 per cent substitution of fly ash (sample No. 174)) is observed to be 940 psi. at 7 days and 1725 psi. at 28 days.

TABLE I.—CHEMICAL AND PHYSICAL ANALYSES OF FLY ASH AS RECEIVED.

	Samples from Essex Station					Sample from Another Utility Company
	Dry Fly Ash Samples Collected at the Precipitators				Wet Fly Ash Sample Collected at Ash Pit	Dry Fly Ash Sample Collected at Precipitator
Date sample received	10/17/38	1/20/39	3/8/39	2/27/40	3/27/40	4/26/40
Sample	No. 69	No. 82	No. 85	No. 170	No. 172	No. 174
Chemical tests:						
Carbon, per cent	9.90	12.24	6.73	6.51	8.01	14.76
Silica, per cent	41.85	34.20	34.30	36.26	36.35	36.64
Iron oxide, per cent	12.70	12.04	23.72	14.22	16.80	9.30
Aluminum oxide, per cent	29.15	21.80	23.70	28.34	19.25	29.10
Calcium oxide, per cent	3.30	6.02	6.20	4.61	10.70	5.05
Magnesium oxide, per cent	....	0.67	1.67	0.42	2.21	2.99
Sulfur trioxide, per cent	....	1.71	2.06	1.23	1.72	0.92
Loss on ignition, per cent	....	12.60	6.75	7.75	13.61	16.80
Physical Tests:						
Specific gravity	2.08	2.34	2.41	2.38	2.39	2.36
Unit Weight, lb. per cu. ft.:						
Dry loose	39.69	42.90	50.50	41.66	40.40	46.08
Dry rodded	41.00	46.00	59.96	48.60	45.45	49.87
Voids (Loose weight), per cent	69.2	70.7	66.4	71.9	72.9	68.8
Sieve analysis (dry), per cent:						
Passing No. 16 sieve	....	....	....	....	97.0[a]	....
Passing No. 50 sieve	....	....	....	....	87.0[a]	....
Passing No. 100 sieve	....	....	....	....	82.0[a]	....
Passing No. 200 sieve	92.0	92.0	90.0	69.0	78.0	93.8
Passing No. 325 sieve	80.0	67.0	42.0	16.0	69.0	75.4
Color	Slate gray	Slate gray	Slate gray	Light brown	Light gray	Slate gray

[a] These larger sizes included small pieces of coal.

Table II summarizes the proportioning, yield, workability and strength results for the various batches of concrete in the first three series of tests. The results for the series 1 and 2 mixes definitely favor sand replacement by dry fly ash as against replacing any of the cement. The results of the two methods of using fly ash in lean mixes are more clearly shown in Figs. 1 and 2. In Fig. 2(*a*) it is seen that the compressive strength continually increases, reaching a maximum at 25 per cent replacement of the sand. At this optimum point, the gain in 7-day strength is 113 per cent as compared with the strength of a plain mix of equivalent cement content; and the workability is more than triple that of the plain mix.

The compressive strengths at the age intervals shown in Table II (series 1) were plotted on semi-log paper, assuming the age as the function varying according to the compound interest law. The curve for 20 per cent substitution was straight, indicating that the values plotted satisfy the compound interest law formula of the general form:

$$Y = Pe^{rX}$$

Values of age and corresponding

strength were substituted in the formula and the constant P and r derived. Further calculation resulted in the following formula for the age-strength relationship of 20 per cent dry fly ash substitution for sand:

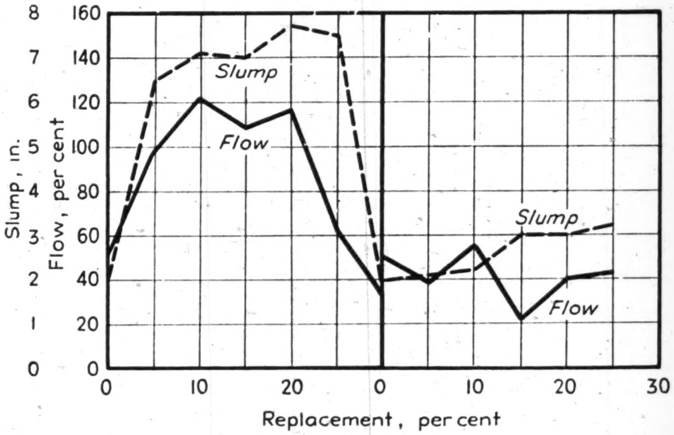
$$Y = 0.583^{e^{0.0024X}}$$

or

$$X = \frac{\log Y + 0.2343}{0.00104}$$

where:

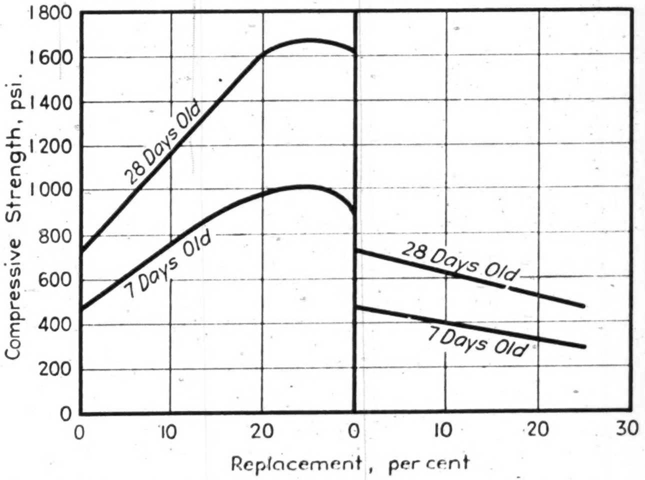
X = compressive strength, and
Y = age in days.



(*a*) Sand replaced by fly ash. (The quantities of cement, gravel, and water maintained constant in each batch.)

(*b*) Cement replaced by fly ash. (The quantities of sand, gravel, and water maintained constant in each batch.)

FIG. 1.—Workability of Concrete Mixes Containing Fly Ash (Sample No. 85).



(*a*) Sand replaced by fly ash. (The quantities of cement, gravel, and water maintained constant in each batch.)

(*b*) Cement replaced by fly ash. (The quantities of sand, gravel, and water maintained constant in each batch.)

FIG. 2.—Compressive Strength of Concrete Mixes Containing Fly Ash (Sample No. 85). (Standard 6-in. diameter by 12-in. high cylinders, moist cured at 70 F.)

In the case of cement replacement in lean mixes the strength continually decreases as the cement is replaced by fly ash; and the improvement in workability is practically negligible.

TABLE II.—WORKABILITY AND STRENGTH OF CONCRETE MIXES IN WHICH FLY ASH WAS USED AS A SUBSTITUTE FOR VARYING PERCENTAGES OF SAND AND CEMENT.

Weights of Materials in Each Batch						Concrete Yield of Each Batch, absolute volume, cu. ft.	Test Results					Variation in 7 Day Strength over Plain Mix, + = Increase − = Decrease, per cent	Remarks
Fly Ash Substituted, per cent	Cement, lb.	Fly Ash, lb.	Sand, lb.	¾-in. Gravel, lb.	Total Water, oz.		Workability		Compressive Strength, psi.				
							Slump, in.	Flow, per cent	7 Day	28 Day	90 Day		
SERIES 1—TESTS USING DRY FLY ASH SAMPLE NO. 85[a]													
Plain Mix—No Fly Ash													
0.......	4.96	0	26.50	41.30	110	0.5496	2.00	50.70	477	725	837	0	Bleeding
Sand Replaced by Fly Ash													
5.......	4.96	1.32	25.18	41.30	110	0.5505	6.50	97.80	654	884	974	+37	Little bleeding
10.......	4.96	2.65	23.85	41.30	110	0.5513	7.25	121.90	672	1008	1888	+41	Very little bleeding
15.......	4.96	3.98	22.52	41.30	110	0.5520	7.00	109.75	902	1432	2118	+89	No bleeding
20.......	4.96	5.30	21.20	41.30	110	0.5528	7.75	116.33	973	1609	2100	+104	Fatty
25.......	4.96	6.62	19.88	41.30	110	0.5536	7.50	62.17	1017	1662	2282	+113	Very fatty
30.......	4.96	7.95	18.55	41.30	110	0.5544	1.75	32.67	884	1627	2728	+85	Too stiff
SERIES 2—CEMENT REPLACED BY FLY ASH[a]													
5.......	4.71	0.25	26.50	41.30	110	0.5500	2.12	38.70	424	654	679	−11	Bleeding
10.......	4.46	0.50	26.50	41.30	110	0.5503	2.25	55.80	354	601	698	−26	Bleeding
15.......	4.22	0.74	26.50	41.30	110	0.5507	3.00	22.25	362	530	600	−24	Bleeding
20.......	3.97	0.99	26.50	41.30	110	0.5511	3.00	40.25	309	575	709	−35	Bleeding
25.......	3.72	1.24	26.50	41.30	110	0.5516	3.25	43.08	301	460	785	−37	Bleeding
SERIES 3—TESTS USING WET FLY ASH SAMPLE NO. 172 (100 PER CENT SATURATION)													
Plain Mix—No Fly Ash													
0.......	4.96	0	26.50	41.30	110	0.5496	2.00	66.60	477	760	833	0	Bleeding
Sand Replaced by Fly Ash													
5.......	4.96	1.98	25.18	41.30	110	0.5505	6.75	105.83	460	760	1000	−4	Bleeding
10.......	4.96	3.97	23.85	41.30	110	0.5513	7.00	143.30	460	822	1730	−4	Little bleeding
15.......	4.96	5.97	22.52	41.30	110	0.5520	8.00	138.75	584	1008	1686	+22	Very little bleeding
20.......	4.96	7.95	21.20	41.30	110	0.5528	7.50	120.10	628	1149	1818	+32	No bleeding
25.......	4.96	9.93	19.88	41.30	110	0.5536	7.00	95.00	619	1132	1922	+30	Fatty
30.......	4.96	11.93	18.55	41.30	110	0.5544	5.25	95.00	601	1167	2048	+26	Very fatty

[a] The above results are shown graphically in Figs. 1 and 2.

The workability of the lean mixes involving the two methods of fly ash substitution are best observed in Figs. 5 and 6. These photographs show the mixes after completion of the flow test. In the mix shown in Fig. 5 considerable bleeding of the mixing water and segregation of the coarse aggregate is very apparent. This same condition exists in the plain mix. Figure 6 shows the plastic condition of the fly ash mix and the absence of any segregation of the coarse aggregate and bleeding of the mixing water.

The results of substitutions of wet fly ash for sand are shown in series 3, Table II. The improvement in early

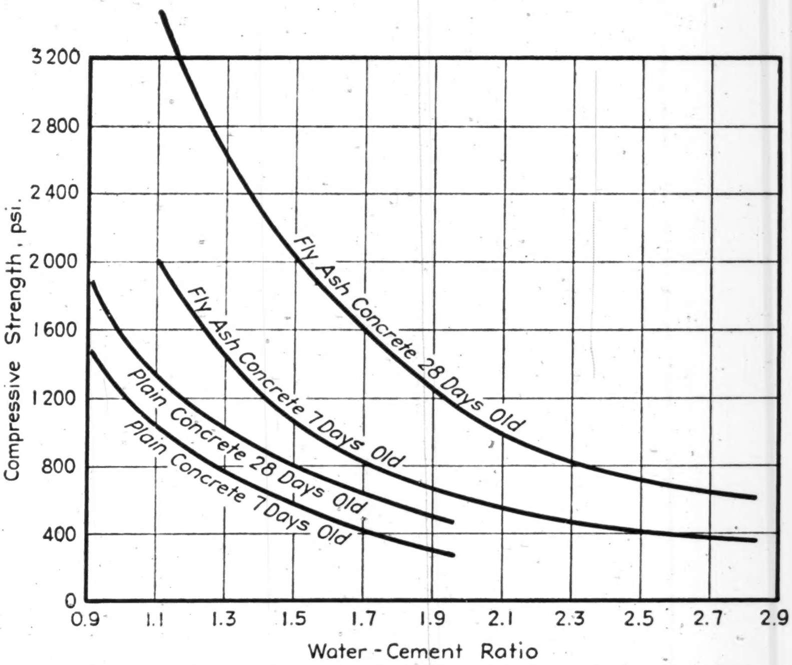


FIG. 3.—Comparative Compressive Strengths of Plain and Fly Ash Concrete Mixtures of Varying Richness.

In the Fly Ash Mixes 25 per cent of the Normal Sand Content was Replaced by an Equivalent Weight of Dry Fly Ash, No. 174.

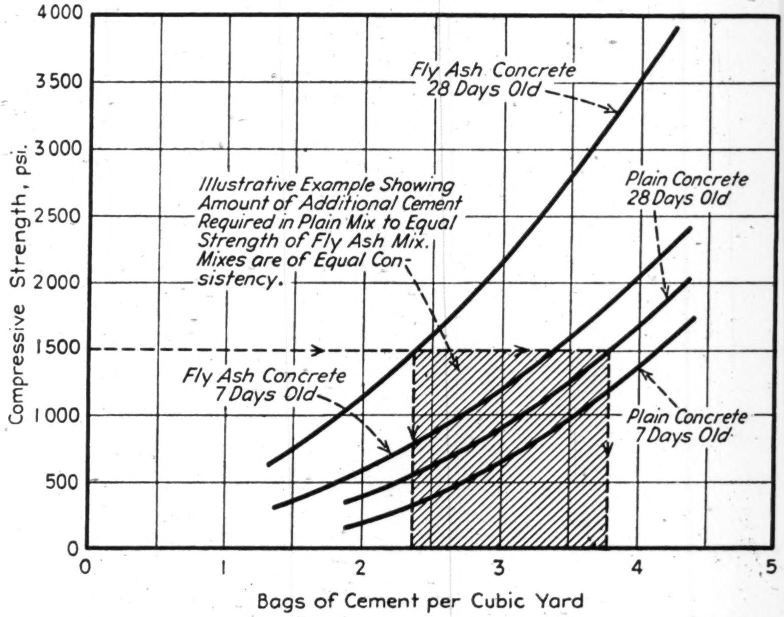


FIG. 4.—Comparison of Plain and Fly Ash Concrete Mixtures Showing Saving in Cement Content per Cubic Yard of Concrete Made Possible by Substituting Fly Ash for 25 per cent of Normal Sand Content.

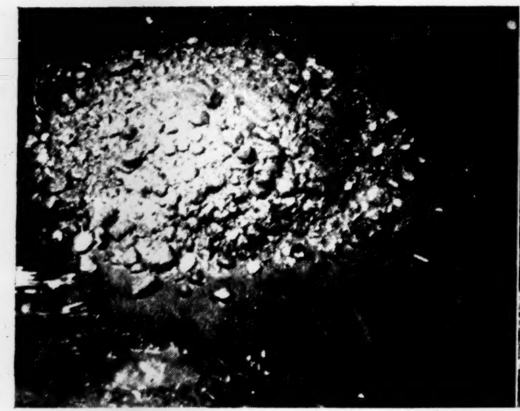


FIG. 5.—Mix in which 25 per cent of the Cement Was Replaced by an Equivalent Weight of Dry Fly Ash.

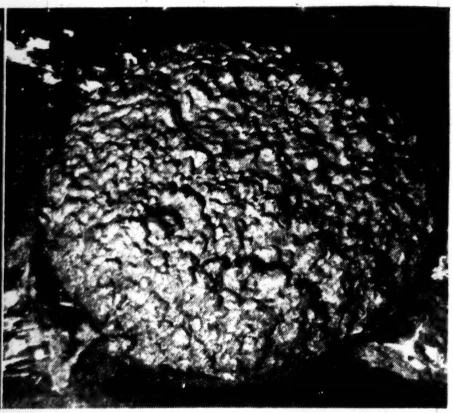


FIG. 6.—Mix in which 25 per cent of the Sand Is Replaced by an Equivalent Weight of Dry Fly Ash.

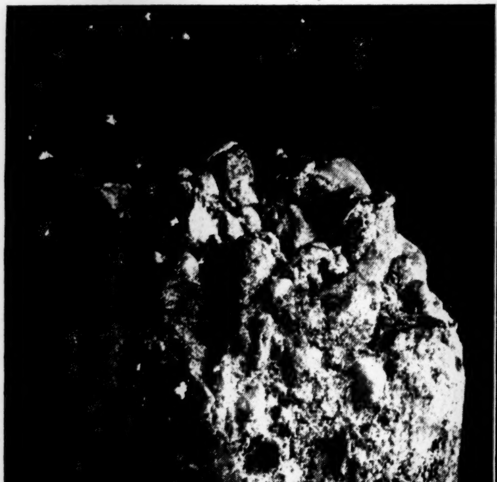


FIG. 7.—Plain Concrete Mix.

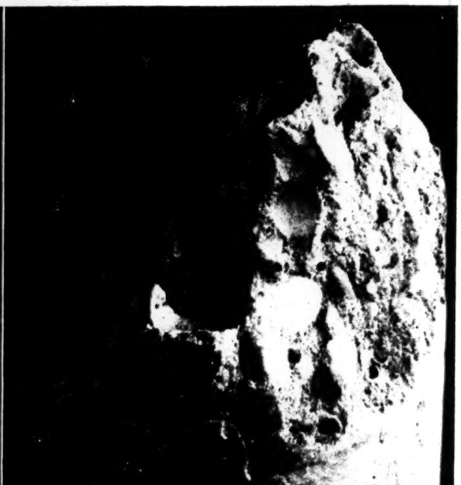


FIG. 8.—Concrete in which 25 per cent Dry Fly Ash Was Substituted for Equivalent Sand.

strength is not so pronounced as in the dry fly ash substitutions. However, the strengths at longer periods of aging do compare favorably with those for dry fly ash. In both the wet and dry fly ash substitutions, the mix was quite plastic at 25 per cent replacement of the sand.

Table III summarizes the workability and strength results of plain and fly ash concrete mixtures of varying richness. In all the fly ash mixes the optimum percentage of dry fly ash substitution for sand was maintained and the richness varied from 1.42 to 3.97 bags of cement per cubic yard. The richness of the plain mixes was varied in approximately the same amount. The results for this series of tests are shown in Figs. 3 and 4. These curves show quite clearly that the 7-day strengths of all the fly ash mixes are greater than the 28-day strengths of the plain mixes of equivalent cement content. The shaded area in Fig. 4 indicates the amount of additional cement required in a plain mix to equal the strength of a fly ash mix. At 1500 psi. this amount is calculated to be 1.4 bags of cement.

TABLE III.—COMPARISON OF PLAIN AND FLY ASH CONCRETE MIXTURES OF VARYING RICHNESS. TEST SERIES 4.

In the fly ash mixes 25 per cent of the normal sand content was replaced by an equivalent amount of dry fly ash No. 174.

Water-Cement Ratio	Bags Cement per yard	Slump, in.	Flow, per cent	Compressive Strength, psi.	
				7 Day	28 Day
		PLAIN MIXES			
0.916	4.18	7.50	131.7	1539	1910
1.177	3.43	7.50	143.4	911	1203
1.367	2.78	6.25	96.6	725	....
1.965	2.06	2.25	36.7	274	477
		FLY ASH MIXES			
1.111	3.97	7.50	95.0	2096	3484
1.315	3.32	7.50	101.6	1450	2653
1.692	2.45	8.75	125.0	831	1698
2.061	2.02	7.50	120.0	566	1052
2.835	1.42	7.50	100.0	354	610

NOTE.—The above results are shown graphically in Figs. 3 and 4.

The density of concrete using a fly ash mix and a plain mix of equivalent cement content can be seen in the representative compression test cylinders shown in Figs. 7 and 8. The porous condition of the plain concrete mix is seen in Fig. 7. The large pores in the surface of the cylinder are the result of evaporation of the excess mixing water. It is to be noted that both of these mixes contain the same amount of cement, coarse aggregate, and water, and that the only difference in the two mixes is that in the fly ash mix 25 per cent fly ash was substituted for sand. Substituting 25 per cent dry fly ash for equivalent sand resulted in a dense concrete and a smooth hard surface as seen in Fig. 8.

Examination of a test manhole poured approximately $3\frac{1}{2}$ yr. ago with fly ash concrete resulted in similar favorable characteristics. The wall surface of the manhole was cleaned by wire brush and then chipped by hammer, revealing a smooth, hard, and dense surface with no signs of deterioration.

The results would indicate that all the improvements in lean concrete mixtures containing fly ash substitutions for sand are principally due to the added paste produced by the combination of the excess mixing water and the fly ash fines. This additional paste reduces the voids and thoroughly coats the surfaces of all the aggregates. The cement paste in plain mixes is apparently not sufficient to realize these benefits.

SUMMARY

The results of the tests may be summarized briefly, as follows:

1. Fly ash substitutions for equivalent weights of sand in lean concrete result in higher strength and greater workability than plain concrete.

2. The optimum point for fly ash substitutions is 25 per cent of the sand content.

3. The bleeding of the mixing water in lean concrete is considerably reduced by fly ash substitutions for sand.

4. Wet fly ash substitutions are not so effective as dry fly ash in producing high-early-strength concrete. However, at longer periods of curing there is little difference in the strength of the mixes containing wet or dry fly ash.

5. The 7-day compressive strength of lean fly ash mixes averages 16 to 34 per cent greater than the 28-day strengths of plain concrete of equivalent cement content.

6. For a specified strength, fly ash mixes require 34 to 48 per cent less cement than plain concrete.

7. The density and surface hardness of concrete containing fly ash substitutions for sand are superior to plain concrete of equivalent cement content.

8. Strength and workability are not effected detrimentally by high-carbon fly ash when the ash is used as a partial substitute for sand in lean concrete.

9. From a disposal standpoint much greater amounts of fly ash may be used by replacing sand rather than cement in lean mixes.

DISCUSSION

Mr. Walter G. Doherty.[1]—In a paper of this kind it would be interesting to know the type of sand used and also its analysis. We have followed in the literature in recent years a great many papers purporting to show that we do need in our sands a certain minimum amount of fines, and some of our specifications now make provision in that respect.

We have found in New York that we not only have to deal with the gradation of the sand, but also the type of the sand; in other words, whether it is a stone sand or a natural sand. That is why I felt that more complete knowledge of the type of sand that was used in your experiments would be of benefit to us.

Mr. Harry A. Frederick.[2]—In reply to Mr. Doherty I must confess that the omission of the sand analysis was quite accidental.

The sand used in our experiments was a natural quartz sand sold in the metropolitan New York area.

The mechanical analysis follows:

Passing 3/8 in. sieve	100 per cent
Passing No. 4 sieve	100 " "
" " 16 "	81 " "
" " 50 "	15 " "
" " 100 "	2 " "

The rodded weight averaged 2850 lb. per cu. yd.

Mr. William S. Elliott.[3]—Mr. Frederick seems to have an answer to several questions that perplex us in New York. It was brought out, just before my rising, that there is a lack of fines in certain sands purchased for concrete use in New York, notably the sands obtained by dredging operations. I understand that the dredging operators waste at least 50 per cent of the product they produce in obtaining gravel because that sand is not marketable as a concrete sand.

At the same time, we have a very serious problem here of disposing of fly ash and fine ash. There is practically no other kind of ash here. We have difficulty in getting cinders for cinder concrete. Well, if that fly ash (which we pay to dispose), added to portland cement (for which we pay a fair price) will give us a concrete having the properties that Mr. Wuerpel and others advocate, with the use of fine sands, I think we have the answer to several problems all at once, and this subject which Mr. Frederick has brought up is very interesting.

Mr. Nicolaas T. F. Stadtfeld.[4]—I should like to ask whether any freezing-and-thawing tests were made on these specimens; in other words, is any of this concrete ever used above the frost line?

The reason I ask that is because in the State of Washington it was found that the addition of carbonaceous materials greatly reduced the resistance to frost action on concrete.

---

[1] Chemist in Charge, Division of Tests, President of the Borough of the Bronx, New York, N. Y.

[2] Assistant Materials Division Chief, Maplewood Laboratory, Public Service Electric and Gas Co., Maplewood, N. J.

[3] Chief, Materials Section, Department of Public Works, The City of New York, New York, N. Y.

[4] Division Engineer, Board of Water Supply, New York, N. Y.

MR. FREDERICK.—The class of concrete studied in our experiments is used entirely for underground structures. Therefore, freezing-and-thawing tests were not considered necessary. However, other investigators have found that fly ash concretes exhibit about the same resistance to freezing and thawing as corresponding plain mixes.

Author's closure, by letter.—The importance of added fines in lean concrete is clearly illustrated in the foregoing data. Richer mixes, involving fly ash substitution for sand, were also investigated with results more or less in general conformity with those for the leaner mixes. Our tests indicate that in both classes of concrete a total fines content (cement, or cement plus fly ash) of at least 564 lb. is essential for optimum results.

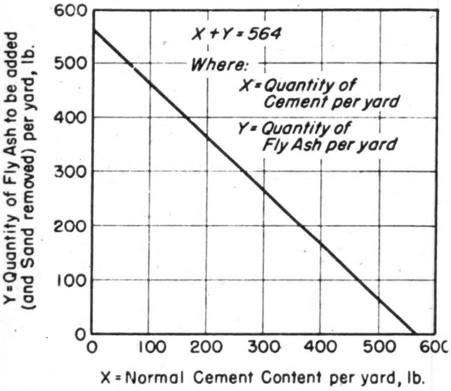


FIG. 1.

The proportions of cement and fly ash for optimum results are shown in the accompanying Fig. 1.

ENTRAINED AIR—ITS EFFECT ON THE CONSTITUENTS OF PORTLAND CEMENT CONCRETE

By Henry L. Kennedy[1]

Synopsis

This paper describes investigations covering the effect of two types of air-entraining agents on the various constituents of portland cement concrete, the object being to assist in a better understanding of the action of air-entraining agents on portland cement concrete. The amount of air entrained by the fine aggregate constituent and two methods of measuring such air are described. The effect of the air-entraining agents on the portland cement constituent is also described. Photomicrographs are shown for both cement and fine aggregate in the presence of the air-entraining agents. Concrete (and simulated concrete) with and without air-entraining agents, are described and illustrated.

When, a few years ago, interest in the possibility of increasing resistance of concrete to freezing and thawing by means of air entrainment was revived, particularly to reduce the scaling of highway pavements, it seemed desirable, in order to obtain a full appreciation of the function of air entrainment in concrete, to study the effects of entrained air on the several individual ingredients of the concrete.

It is an irrefutable fact that markedly better performance, particularly for some exposures of concrete, results from carefully controlled air-entraining concretes. Such concretes are more plastic and show less bleeding. Benefits to other properties of concrete will unquestionably be revealed with further investigation. However, in some cases, results have been obtained which indicate the desirability of a more thorough knowledge of the function of air-entraining agents on the various ingredients of portland cement concrete.

It is well known that the durability of ordinary concrete (without air-entraining agents) as measured by freezing and thawing becomes consistently better as the water-cement ratio is lowered. Some air voids are present in all concrete even in the absence of air-entraining agents. But since such air is comparatively negligible, the total volume of water plus air is largely a function of the water content. It follows that for ordinary concrete, if the total volume of water plus air is decreased, the durability will increase.

But when additional air in the form of well-distributed bubbles has been entrained in concrete by means of an air-entraining agent, the same rules do not necessarily hold. In this case the total volume of water plus air is largely influenced by the amount of entrained air

---

[1] Manager of Cement Division, Dewey & Almy Chemical Co., Cambridge, Mass.

present. Many tests with air-entraining concretes have shown that durability as measured by freezing and thawing generally becomes consistently better as the total volume of water plus air is increased.

This paradoxical situation indicates clearly that when air-entraining agents are present, a new mechanism is set up in the concrete structure which must govern the durability as measured by freezing and thawing.

It is the purpose of this paper to point out some of the indications resulting from a study of the portland cement and aggregate constituents of concrete, especially as to differences in particle size in the presence of two classes of air-entraining agents, namely, (1) resinous materials and (2) water soluble wetting agents such as sulfated alcohols and sulfonated hydrocarbons. It is further the purpose of this paper to point out (1) the danger of uncontrolled air and (2) the desirability of studying more completely the effect of air-entraining agents in rich mixes. The amount of air-entraining agent used in this investigation varied from 0.01 per cent to 0.05 per cent of the cement.

EFFECT OF AIR-ENTRAINING AGENTS ON NEAT PORTLAND CEMENT

Percentage of Added Air Entrained in Neat Cement:

With a normal but constant type of mixing, the results of a series of tests with four air-entraining agents of the type under the scope of this investigation and fourteen cements having an average surface area of 1750, indicate that in general 1 ± ¼ per cent added air is entrained in neat portland cement paste for each added increment of 0.01 per cent of the agent.

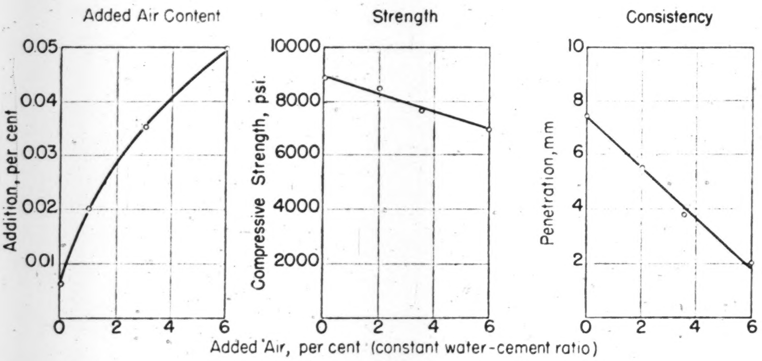


FIG. 1.—Effect of Various Quantities of Air-Entraining Agent and Entrained Air On Compressive Strength and Consistency of Neat Cement.

All four agents used did not entrain exactly the same amount of added air with all fourteen cements. Apparently composition, fineness, and, possibly, particle size distribution influenced the action of the air entraining agent on the portland cement paste. But for the purpose of this discussion, the entrainment of approximately 1 per cent added air per 0.01 per cent additional air-entraining agent, is considered to be normal (Fig. 1).

Consistency of Neat Portland Cement:

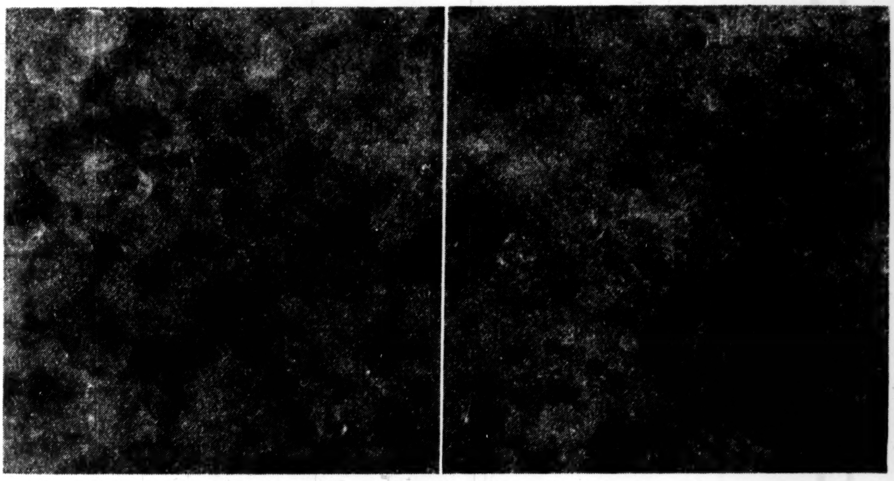
The consistency of a neat portland cement paste (as measured by penetration of the Vicat needle) was in general progressively stiffened as increasing amounts of the air-entraining agent were added (Fig. 1). Examination of cement paste under E. Leitz' "Ultropak" microscope with oblique illumination, shows that the air which is known to be present by actual measurement, is not readily discernible (Fig. 2). It is suggested that the entrained air may be adsorbed on the cement particles.

The fact that the consistency of concrete (as measured by the slump test) is improved as increasing amounts of air-entraining agent are added, presents an interesting problem.

Strength of Neat Cement:

Repeated tests have shown a consistent decrease in strength of neat cement specimens with increased percentages of air-entraining agent (Fig. 1). But since a corresponding increase in air content is noted, the reduction in strength is more likely due to the entrained air than to the agent.

Because the increase in air content in neat cement paste usually results in a greater consistency (stiffer paste), it is obvious that the attendant decrease in strength of neat cement cannot be compensated for by a reduction in water. It is probable that the air entrained in the cement paste constituent of concrete contributes toward reducing the strength of the concrete. Consequently, it may be expected that as the cement content of a concrete mix increases, the effect of the air-entraining agent upon strength of concrete will become more pronounced.



Without air-entraining agent. With air-entraining agent.

FIG. 2.—Neat Cement Paste With and Without Air Entraining-Agent Using Ultropak Microscope With Vertical Illumination (× 500).

Durability of Neat Cement:

It is well known that neat cement specimens expand and contract excessively with changes in moisture content, which must cause large stresses especially at the surface. Also, freezing and thawing causes large stresses to be developed and these stresses may cause local disruptions near the surface of the neat cement specimen. Both of these actions tend to cause progressive scaling inward.

An investigation involving eleven different cements, both with and without air-entraining agents, indicates that neat specimens containing air-entraining agents are less durable than the companion untreated specimens (Table I). This is in line with the lower strengths of the treated cements but, more important, it seems to indicate that the air voids in the treated cement are not available for relief of expansion due to freezing either because they are insufficient in size or possibly because the added air is adsorbed on the fine particles.

It is worthy of note that failure of the treated specimens occurred through excessive scaling of all faces. Scaling was more pronounced on the top face of the specimen as cast and was least noticeable on the bottom face. The cores in all cases were sound, as measured by dy-

TABLE I.—EFFECT OF AIR ENTRAINING AGENTS ON NEAT CEMENT SPECIMENS.
Freezing and Thawing in Calcium Chloride.

Cement		Air-Entraining Agency, per cent	Density	Total Air, per cent	Initial Weight, g.	Number of Cycles	Final Weight, g.	Loss, per cent by weight	Remarks
No.	Type								
1	II	0	2.25	0.5	489.08	200	448.90	8.2	Slow-speed stirrer 500 rpm.
		0.03	2.14	5.3	460.79	200	395.50	14.2	
		0	2.22	1.7	492.85	200	445.60	9.6	High-speed stirrer 10 000 rpm.
		0.03	2.05	9.3	435.41	200	357 55	18.1	
2	II	0	2.23	1.3	512.50	180	428.81	16.3	Hand mix, A.S.T.M. Method C 77 – 40[a]
		0.03	2.19	3.1	504.10	180	367.00	27.2	
3	II	0	2.23	1.3	512.60	180	463.51	9.6	
		0.03	2.16	4.5	504.10	180	404.37	19.8	
4	I	0	2.23	1.3	478.20	140	480.0	+0.2	
		0.045	2.14	5.3	481.43	140	462.53	3.9	
		0	2.23	1.3	496.20	140	491.24	1.0	
		0.045	2.14	5.3	473.66	140	443.94	6.2	
5	I	0	2.23	1.3	479.60	120	455.73	5.0	
		0.03	2.15	4.8	471.60	120	413.30	12.4	
		0	2.24	0.8	478.40	120	456.64	4.6	
		0.03	2.15	4.8	464.60	120	409.25	11.9	
6	I	0	2.20	2.6	469.55	115	425.10	9.5	
		0.03	2.15	4.8	447.00	115	369.00	17.4	
7	I	0	2.19	3.1	468.84	110	430.35	8.2	
		0.03	2.15	4.8	475.75	110	386.10	18.8	
8	II	0	2.26	0	491.65	110	390.27	20.6	
		0.03	2.20	2.6	479.45	110	367.51	23.3	
9	II	0	2.24	0.8	496.40	110	490.22	1.2	Slow-speed stirrer 500 rpm.
		0.03	2.14	5.3	463.55	110	69.33	85.0	
		0	2.20	2.6	479.25	110	386.24	19.3	High-speed stirrer 10 000 rpm.
		0.03	2.04	9.7	423.00	110	49.67	88.3	
10	I	0	2.20	2.6	469.25	70	448.75	4.4	Hand mix. A.S.T.M. Method C 77 – 40[a]
		0.03	2.15	4.8	456.02	70	416.70	8.6	
11	I	0	2.20	2.6	473.16	70	460.37	2.7	
		0.03	2.14	5.3	455.75	70	424.95	6.9	
		0	2.20	2.6	471.60	70	465.80	1.2	
		0. 3	2.14	5.3	452.92	70	427.30	5.7	

NOTES.—Water-cement ratio, for all tests = 0.25 by weight.
10 per cent $CaCl_2$ solution used for each series.
Test specimens 1.5 by 1.5 by 6.0 in. prisms.
All specimens cured 1 day molds, 6 days moist, 6 days laboratory air, and 1 day moist except cement No. 9 which specimens cured 7 days moist.

[a] Standard Methods of Sampling and Physical Testing of Portland Cement, 1942 Book of A.S.T.M. Standards, Part II, p. 33.

namic modulus, even when the specimen was reduced to one-third its original size.

EFFECT OF AIR-ENTRAINING AGENTS ON FINE AGGREGATE

The following investigation was carried out to determine the degree and function of entrained air on fine aggregate.

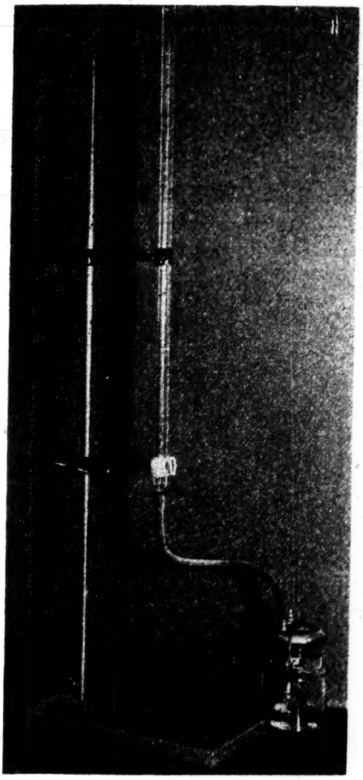


FIG. 3.—Apparatus Used in Determining Air Content With Alcohol Water Solution (Method II).

Material Used:

A local washed sand known as Scituate sand, was used for this investigation. The Scituate sand was graded from No. 14 to passing a No. 100 sieve to provide individual sizes.

Two air-entraining agents were used throughout; one a resinous material and the other a water soluble sulfonated hydrocarbon, both in solution form.

Test Methods:

The procedure consisted of making a mixture of 250 g. of sand and 60 ml. of water, with and without the air-entraining agent. Water was added to the sand and allowed to stand 30 sec. in a 400-ml. beaker, followed by 2 min. of uniform vigorous stirring with a $\frac{7}{8}$-in. spatula held in a vertical position.

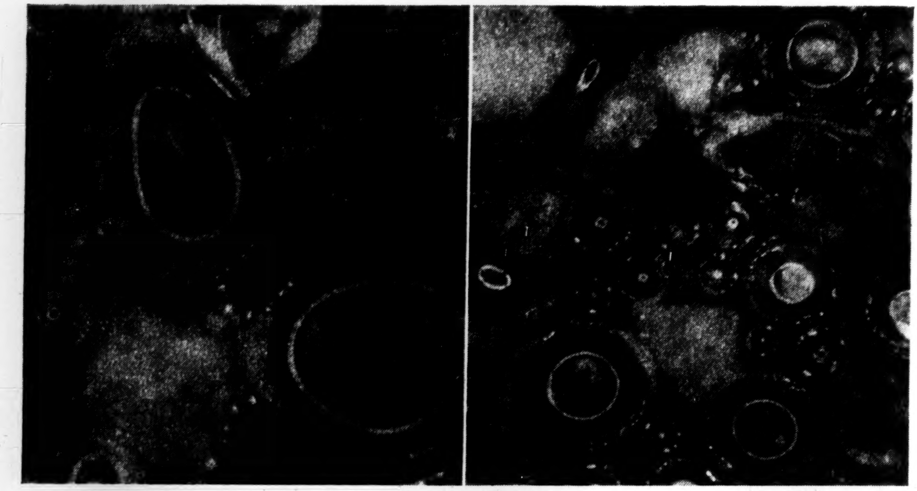
Two methods were used to check the amount of air entrained.

1. The first was a density measurement of the wet mix of sand and water, utilizing a small container of approximately 150 ml. capacity. The percentage added entrained air was determined from the observed difference in weights of the treated and untreated samples. The total air was calculated from the theoretical weights of the materials used.

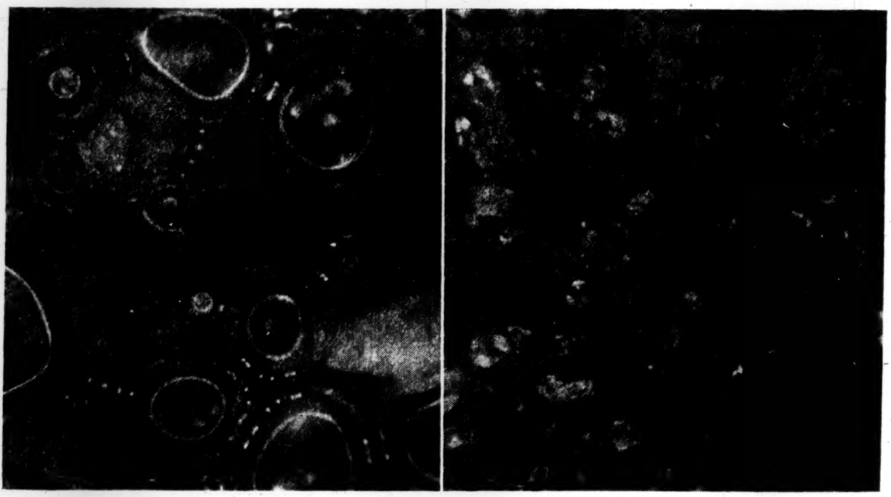
2. The second method was actually to measure the amount of air entrained in the wet mix of sand and water by the use of the apparatus shown in Fig. 3. A standard mason jar was used with a specially cast bronze cap which had two openings, one for venting the system and the other connected to a 100-ml. burette by means of rubber tubing.

The mixture was carefully placed in the mason jar, levelled off and sealed with a thin layer of paraffin. The space above the paraffin was filled with a 25 per cent alcohol solution in water. The jar was then capped, the burette attached, and the entire system filled to the 100-ml. mark with the alcohol solution, taking due care to remove all free air from the system. The use of a glass container makes this operation one of simple observation.

The paraffin seal was then broken by agitation of the jar. Continued agitation of the jar by rolling on a smooth



No. 30 to No. 50 sieve.   No. 50 to No. 100 sieve.



No. 50 to No. 100 sieve.   No. 100 to No. 200 sieve.

FIG. 4.—Fine Aggregate in the Presence of an Air-Entraining Solution Using Ultropak Microscope With Vertical Illumination (X 65).

TABLE II.—AMOUNT OF AIR ENTRAINED BY DIFFERENT SAND FRACTIONS IN THE PRESENCE OF AN AIR-ENTRAINING AGENT.

Sieve Size	Total Air, per cent									Added Air, per cent	
	No Air-Entraining Agent Present, avg.	With Air-Entraining Agent Present								With Air-Entraining Agent Present	
		Method I				Method II				Method I, avg.	Method II, avg.
		1	2	3	avg.	1	2	3	avg.		
No. 14 to No. 30	4.5	14.8	14.6	13.3	14.2	15.7	15.5	15.4	15.6	9.7	11.1
No. 30 to No. 50	5.9	20.0	21.0	22.3	21.1	21.6	22.2	21.0	21.6	15.2	15.7
No. 50 to No. 100	6.8	24.0	23.2	24.2	23.8	24.9	26.0	25.3	25.4	17.0	18.6
Passing No. 100	6.6	7.9	8.6	9.0	8.5	10.3	9.6	9.8	9.9	1.9	3.3

surface permitted all the air in the mixture to escape through the burette. The total entrained air of the mixture was determined by observing the reduction of solution in the burette and correcting the total decrease in volume for change in volume of solution due to the presence of alcohol.

The alcohol water solution was used because it helps collect all the free air in the mix in large bubbles thus preventing the formation of excessive foam which might mask the reading.

It is interesting to note that the amount of air entrained with fine aggregate in the presence of an air-entraining agent reaches an optimum with the No. 50 to No. 100 size sieve. It is most significant that sand passing the No. 100 sieve entrains very little added air (Table II).

Microscopic Studies:

Microscopic studies were made of the same sand fractions with and without the air-entraining agent using E. Leitz' "Ultropak" microscope with oblique illumination. Photomicrographs shown in Fig. 4 exhibit clearly the mechanism by which sand in the range between No. 30 to No. 50 and No. 50 to No. 100 sieve, is plasticized when air is entrained by the class of agents used in this investigation. The seemingly perfect spheres or ball bearings of air bubbles cling to and separate the sand particles, thus forming an excellent means of lubrication.

But when the particle size is finer than the No. 100 sieve, no air bubbles are discernible (Fig. 4) despite the fact that some air is present (Table II), again suggesting that the air may be adsorbed on the fine particles.

EFFECT OF AIR-ENTRAINING AGENTS ON COMBINED FINE AND COARSE AGGREGATE

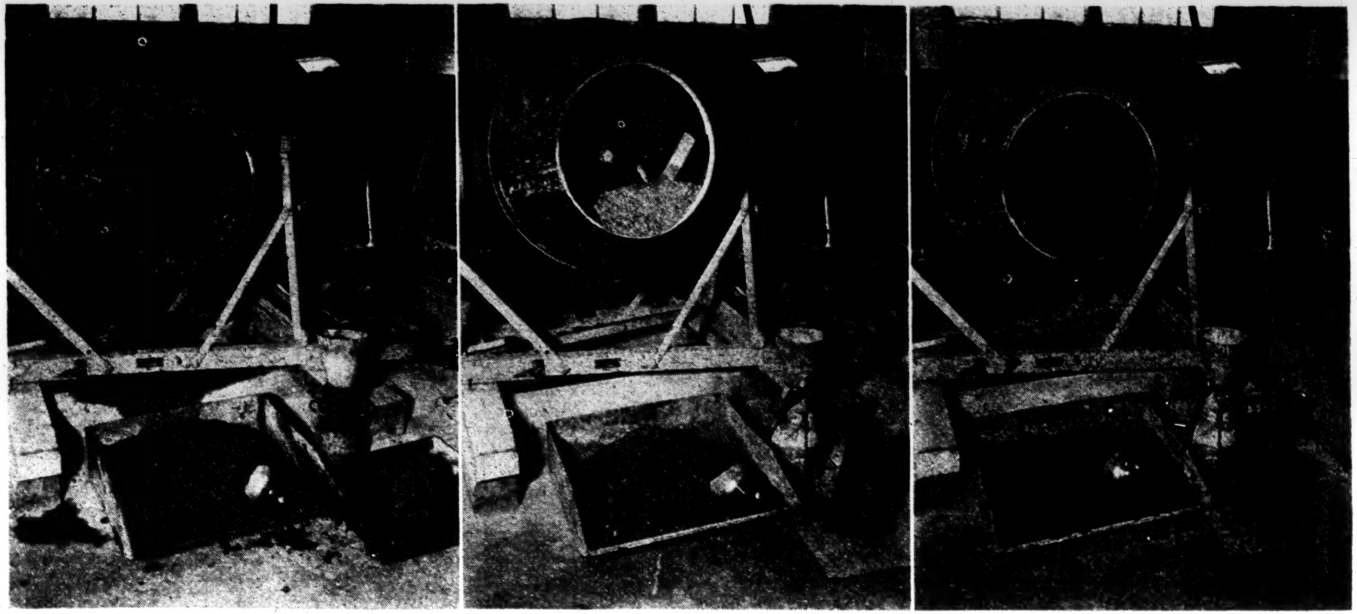
The following investigation was carried out to determine the degree and function of added entrained air with the combination of fine and coarse aggregate in the presence of an air-entraining agent. A Rex drum-type half-sack mixer operating at a speed of 18 rpm., was used for this investigation. A concrete mix of 1:2.5:3.5 proportions and a corresponding simulated concrete omitting the cement, were made for the purpose of comparing appearances. The sand and gravel were both bank run material, the sand having a fineness modulus of 2.62 and the gravel 7.05. The maximum size aggregate was 1½ in.

For the actual concrete mix, type I cement with a surface area of 1750 was used. A water-cement ratio of 0.60 by weight and a mixing period of 2 min. produced a slump of 6 in. (Fig. 5(*a*)), without air-entraining agents.

For the corresponding simulated mix, the same amount of sand and gravel were added to the mixer but the cement was omitted. The mixer was started and sufficient water added to produce a surface damp condition, hence a very harsh crumbly mix. A 2-min. mixing period produced a slump of 0 in (Fig. 5(*b*)), without air-entraining agents.

The mixer was again started. The air-entraining agent was then added in solution form in an amount of 0.005 per cent by weight of the total aggregate. This is equivalent to the amount of air-entraining agent available in a 1:6 concrete mix, assuming 0.03 per cent of the agent on the cement. For 2 min. after adding the agent, the mix continued harsh but during the next 2 min., the mix developed a flowing consistency. No segregation was apparent. The larger aggregates were covered with a paste of air and sand. The mix produced a slump of 6 in. The measured added air content was 10 per cent.

The above simulated concrete mix was repeated except that a pinch of dry carbon black was added to the mix simply



(*a*) Actual concrete mix 1:2.5:3.5, 0.60 water-cement ratio, 6-in. slump.

(*b*) No cement, sand and gravel weights same as (*a*), surface damp.

(*c*) Simulated concrete, same mix as (*b*) except air-entraining agent added.

FIG. 5.

to impart a cement-like color. After mixing for the same period, the mix produced a slump of 6 in. and an added air content of 10 per cent (Fig. 5(*c*)).

It would be difficult indeed to tell which product was a six-sack mix and which was a zero-sack mix. Based on workability and placability, the zero sack mix with the air-entraining agent would be selected in preference to the actual concrete mix of the same slump without the air-entraining agent. Of course, if this mixture is allowed to stand long enough for the air to dissipate, it reverts to a harsh sand and gravel mix.

It is obvious that an excellent appearing concrete can be made with a very low cement content if sufficient added air is entrained with the mix. But the strengths would be so low that despite the relief of stresses provided by the added air, the concrete would not be serviceable. Strength is still a requirement of portland cement concrete, and air is not a substitute for portland cement.

SUMMARY AND DISCUSSION

It is well known that good concretes containing well-distributed air voids are more plastic, show less bleeding, and have superior resistance to freezing and thawing. It is now generally conceded that these properties are attributable to the entrained air and not to some hidden property of the agent. Some decrease in strength is anticipated and tolerated for highway concrete where strength is still sufficient and where the tendency to eliminate scaling is most important.

From the limited scope of this investigation, it is indicated that all the air entrained in concrete is not beneficial. It has been shown that the air which is entrained in the cement constituent does not contribute to durability. Since concretes containing entrained air will give greater durability as measured by freezing and thawing and since the air entrained in the portland cement constituent does not contribute to this durability, it is apparent that the air entrained in the fine aggregate must be responsible for the enhanced properties of the concrete. This seems to answer in part at least, why air-entraining agents may be more efficient in lean mixes than in rich ones.

The presence of well-distributed air bubbles which are introduced by the air-entraining agent on the fine aggregate provides an explanation for the mechanics of improved plasticity. For a given percentage of air-entraining agent, and constant mixing conditions, the quantity of air entrained by the aggregate is a function of the particle size of the aggregate, the optimum range being between the No. 30 and No. 100 sieve sizes. A small amount of air is entrained by fractions smaller than No. 100 sieve. If the air which is known to be present in the sand passing a No. 100 sieve is not present as free air bubbles, it is suggested that such air may be adsorbed on the fine aggregate thus contributing in no way to plasticity or durability.

Although air entrained in concrete is unquestionably beneficial, it seems advisable to limit the amount of such air. Excessive amounts of air will permit large reductions in the water-cement ratio, yet the net reduction in strength may be too great. Furthermore, excessive air produces excessive plasticity and there is a real danger that the inexperienced user of air-entraining concrete may inadvertently reduce the cement content to an undesirable point because of the excellent appearing concrete. Some reduction in strength may be tolerated, but there is a limit beyond which the beneficial effect of entrained air may be outweighed by lack of sufficient strength to withstand the stresses due to wear and applied loads.

A likely explanation of the resistance to freezing and thawing of a concrete containing entrained air is shown diagrammatically in Fig. 6. The presence of available air voids will relieve the inward pressure as freezing and thawing progresses, since such pressure tends to lower the freezing point and require only space for the water to creep inward.

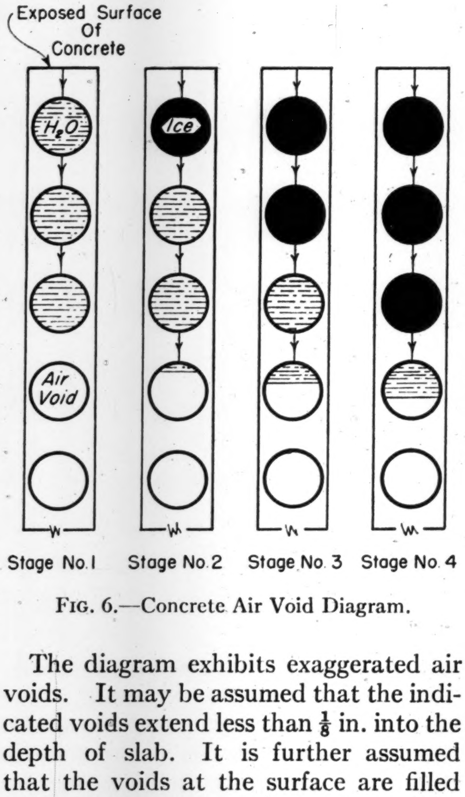


FIG. 6.—Concrete Air Void Diagram.

The diagram exhibits exaggerated air voids. It may be assumed that the indicated voids extend less than $\frac{1}{8}$ in. into the depth of slab. It is further assumed that the voids at the surface are filled with water at stage 1. When the water in the outer void freezes, pressure is developed forcing the excess water (approximately 10 per cent) through the permeable concrete to a free void where the pressure is relieved as shown in stage 2. Stages 3 and 4 show progressive freezing and relief of inward pressure. If insufficient voids are not available, disruption must follow.

CONCLUSIONS

Though it is apparent that further work should be done along the lines reported here, certain tentative conclusions may be drawn at this time, due consideration being given to the limited scope of the data and types of air-entraining agents studied.

1. The amount of air entrained in a concrete may be varied by the gradation of the fine aggregate constituent even though the amount of air-entraining agent remains constant. The No. 50 to No. 100 sieve size seems to entrain the most air.

2. It seems possible that the importance of the presence of a minimum amount of sand passing a No. 100 sieve which is a real factor for many ordinary concretes, may be minimized when air-entraining agents are used.

3. One of the principal dangers of excessive entrained air which produces excessive plasticity of concrete, is the invited or inadvertent reduction in cement content to the possible detriment of other properties than resistance to freezing and thawing.

4. The effect of air-entraining agents on the neat cement constituent points to the desirability of further research with air-entraining agents in the rich mix range.

DISCUSSION

MR. F. B. HORNIBROOK.[1]—Figure 6 presented by the author illustrating a possible mechanism of the role played by air-entrainment in increasing frost resistance calls to mind some studies at the National Bureau of Standards on the pore spaces in concrete. The total pore space was determined with an air-expansion porosimeter, and the so-called easily fillable pore spaces were taken as the spaces filled during 24 hr. immersion in water at room temperature. The ratio of easily fillable pore space to the total pore space ranged from 0.7 to 0.85 for a good grade of normal concrete. When an air-entraining cement was used in the concrete, however, that ratio decreased markedly, reaching a value as low as 0.4 when the air entrainment was as high as 8 to 10 per cent. It is indicated accordingly that concrete containing entrained air, even though provided with opportunity to become saturated, may still retain a considerable volume of unfilled pore space. The mechanism described by the author seems therefore entirely logical.

MR. CHARLES E. WUERPEL.[2]—Some experiments were conducted in our laboratory, we being very much interested in the facility with which the discrete bubbles of air engendered by the use of the air-entraining agent might be saturated or become filled with water after placement and hardening of the concrete. The only way we could approach such a study was by reducing the temperature of the specimens saturated with water under reduced pressure to well below zero in order to fix any moisture present in the voids in the form of ice so that no change would occur in water content following rupture of the specimen to permit inspection of the interior. Ruptured sections of specimens so treated were examined under the microscope at a temperature below 0 F. The work was conducted by Mr. Rexford of the laboratory staff who found that none of the voids were completely filled with water (ice) despite every effort at saturation. The voids were almost filled with water in the very surface film of the specimen, but none of the voids were completely filled and those in the interior were usually not more than half-filled. The results of this investigation support the conception given in the diagram as approaching factual conditions. The air-voids in concrete or mortar may be relatively impermeable under ordinary pressures, but the pressure induced by freezing of concrete or mortar from the outside inward may be great enough to force water into the voids and relieve the pressure created by the formation of ice around the surface of the voids. It may be possible that compression of the air in the voids may generate sufficient pressure to expel the water when the thawing of the concrete occurs. The fact that we have not observed any air voids completely filled with water or ice suggests that the compression of the air in the voids prevents complete filling with water.

---

[1] Materials Engineer, National Bureau of Standards, Washington, D. C.

[2] Engineer-in-Charge, Central Concrete Laboratory, Corps of Engineers, U. S. Army, Mount Vernon, N. Y.

It should be recommended very strongly that the air-entraining agent, *per se*, is not a means of conserving cement. The cement factor should not be reduced. Instead, the water-cement ratio should be reduced which is made practicable by the additional workability provided and thereby approximate the strength obtained normally with similar cement without the air-entraining agent but with a greater water ratio.

The thought has been a little bit too general—that when an air-entraining agent is used, as it should be used, it must be accompanied by the sacrifice of a material amount of strength in concrete. That has been proven not to be so in a very wide use by the Corps of Engineers. I can cite a number of cases, but the pavement for the Rome Air Depot is outstanding, where Vinsol resin was first used on a major scale and was watched very closely.

There, the water-cement ratio was reduced to 4.80 gal. per bag, where a $5\frac{1}{2}$ gal. water-cement ratio would have been required with plain cement. The cement factor was $5\frac{3}{4}$ bags per cubic yard, which would have had to be used with the higher water-cement ratio had Vinsol resin not been employed. The concrete was supposed to develop 4500 psi. in 28 days, before the use of Vinsol resin had been contemplated. With the reduction of the water-cement ratio, the concrete in the structures developed 5115 psi. in 28 days as measured by the conventional 6 by 12-in. cylinder. Therefore, full parity in strength was achieved.

The pavement was cored about 90 days after completion of the work and the average compressive strength of the 193 cores was 6655 psi. At the time of testing, the cores varied in age from 90 to 180 days.

Now, certainly in that case, where the cement content was not increased, it cannot be said that there was a sacrifice in strength.

That applies equally well to other structures built by the Corps of Engineers, now numbering in excess of 168 separate uses of Vinsol resin cement. There have been only five cases where the strength has been below the specified requirements—and in each one of those, the air content was completely out of hand. It was not 1 per cent or 2 per cent. It was not in the order of 5, 6, 7, or 8 per cent. It was in the order of 12 to 16 per cent. Photomicrographs were made of that concrete, and in every case the particles of coarse aggregate (which are mostly clearly seen) were completely surrounded by air voids. The coarse aggregate actually floated in the air voids which surrounded those particles. Now, that, of course, is entrainment of air to an absurd degree, and that is why we felt that we had to improve the means of control of Vinsol resin.

However, I should like to emphasize that the possibilities of the use of Vinsol resin are too great to damn it by continuing to believe that its use entails a necessary sacrifice of strength, either flexural, compressive, or, as the tests indicate clearly, in the bond strength to steel. There is little doubt, however, that the future investigations will cause the development of air-entraining compounds which will possess accelerators which will more than compensate for the acknowledged effect of entrained air, *per se*, on the strength of concrete.

MR. D. S. COLBURN.[6]—I should like to know what strengths Mr. Wuerpel got without the air-entraining agent in cement.

MR. WUERPEL.—You mean at Rome? We didn't use it in significant amounts.

MR. COLBURN.—Well, then you are

---

[6] Vice-President, Marquette Cement Manufacturing Co., Chicago, Ill.

ERRATA

Due to a printer's error, pages 832 and 833 have been incorrectly numbered and therefore appear transposed in this book.

MR. A. T. ROGERS.[3]—If I understood Mr. Kennedy correctly, he said in his paper that it was the particle sizes between the No. 30 and the No. 100 sieves that entrained the most air. I have just run up against a practical problem here in connection with a masonry mortar.

The masonry cement contains a stearate and a plasticizing agent, so that, with masonry sands obtained by washing out of concrete sands, there is about 10 per cent air in a 1:3 mix. On that basis, where the mortar is machine-mixed in a ready mix truck, we always allow for 2½ cu. ft. of entrained air.

Based on the data that I had from previous jobs, I gave the mortar contractor figures in which he could assume this 2½ cu. ft. of air, and he delivered about a thousand yards of mortar. We received a complaint from the brick contractor that this yield was short, so we ran a check yield on this mortar and found that we were getting but 25 cu. ft., which was approximately what we would get by calculating out the materials based on their respective bulk specific gravities without allowance for entrained air.

Now, in examining this mortar, there was no evidence of any air bubbles coming out of it whatsoever. The sand used had about 90 per cent passing the No. 16 sieve with the bulk of it between the No. 30 and the No. 100 sieves and about 8 per cent passed the No. 100 sieve, which is all in the particle sizes that Mr. Kennedy mentioned. We have not completed the analysis of the sand, but the organic test was satisfactory to start with, and I should like to ask Mr. Kennedy what he thinks about that.

MR. HENRY L. KENNEDY.[4]—Since the sand gradation noted as being present by Mr. Rogers seems ideal for the entrainment of air in the presence of air entraining agents similar to those discussed in this paper, namely, resinous materials and water-soluble wetting agents such as sulfated alcohols, it is suggested that possibly there was a deficiency in the amount of plasticizer present or possibly that the mixing was not sufficient.

The effect of both stearates and tallow on the aggregate may vary considerably from the types investigated. I have no firsthand information available for these materials.

MR. M. A. SWAYZE.[5]—The function of the entrained air bubbles is first to reduce the water-cement ratio. The bubbles act as substitutes for sand grains and by being non-absorbent, rounded and elastic promote workability in the concrete with less water. In identical mixes, the water-cement ratio drops whenever air entraining cement is substituted for a corresponding normal portland cement.

However, since the bubbles act similarly to sand, the change from normal portland cement to air-entraining cement in any normal concrete mix will yield an oversanded batch. Mixes should therefore be redesigned when an air-entraining cement is used. A good rule is to take out 1 per cent of sand for each per cent of air entrained. Since sand has the highest water requirement in the mix next to the cement, removal of it will decrease the water-cement ratio still further.

MR. WUERPEL.—As indicated by my previous statement that the discrete air-voids in concrete are not filled with water even after considerable effort is made to fill them by pressure, absorption of mixing water by the air-voids does not constitute a means of reducing the net water-cement ratio used in the concrete. But as Mr. Swayze so effectively stated, the water-cement ratio should be reduced in the design of the mixture.

---

[3] Manager, Technical Service Dept., North American Cement Corp., New York, N. Y.

[4] Manager, Cement Div., Dewey and Almy Chemical Co., Cambridge, Mass.

[5] Director of Research, Lone Star Cement Corp., Hudson, N. Y.

just dealing against a theoretical value and not an actual one?

MR. WUERPEL.—Yes, except for the fact that, as I stated, the mixture was set up first using plain cement. We designed this mix in the laboratory to provide a cylinder strength of 4500 psi., but we placed only a very small amount of that concrete in the project.

TABLE I.

Project	Cement	Number of Cores	Age	Compressive Strength, psi.	Per cent of All Portland	Cement-Water Ratio
No. 2804–01	All portland	15	150	5803		0.621
		10	707	7155		
	Blend	45	150	5091	87.7	0.638
		10	702	5364	75.0	
	Vinsol resin	5	150	4877	84.0	0.679
		6	696	6034	84.3	
No. 4507–04	All portland	34	150	5536		0.615
		8	717	6604		
	Blend	39	150	4544	82.1	0.589
		8	715	5438	82.3	
	Vinsol resin	10	150	3999	72.2	0.646
		6	708	5111	77.4	
No. 5203-09	All portland	28	150	4691		
		6	1053	5841		
	Blend	6	150	4170	88.9	
		5	1062	5445	93.2	
	Vinsol resin	5	150	4503	96.0	
		5	1063	5265	90.1	
No. 8001–03	All portland	21	150	5707		0.606
		8	690	7290		
	Blend	24	150	4690	82.2	0.602
		8	693	6157	84.4	
	Vinsol resin	8	150	4019	70.4	0.627
		6	691	4713	64.6	

MR. COLBURN.—But you are still getting a theoretical value in the field and not an actual one.

MR. WUERPEL.—Not a theoretical value, but, perhaps, a theoretical relationship between the strength of plain-cement concrete and Vinsol-resin-treated-cement concrete. It is a fact, however, that the cement content was not increased because of the use of Vinsol resin. The project specifications required a cement factor of 6.0 bags per cubic yard and an actual factor of only 5.75 bags per cubic yard was used.

MR. F. C. LANG.[7]—The Minnesota Highway Department constructed about twenty-five miles of experimental concrete pavements in 1941 and about a half mile in 1940. Three different types of cement were used on these projects. The three types were all portland cement, 15 per cent portland cement by weight replaced by an equivalent absolute volume of natural cement, and Vinsol resin treated portland cement. No change was made in the proportions of cement, fine, and coarse aggregate. The cement-water ratio used was to give workability for the fixed proportions used. The aggregates, equipment, and contractor's organization were the same for each project. The accompanying Table I shows the compressive strength of cores from each project at two ages and also the cement-water ratio used.

---

[7] Engineer of Materials and Research, Minnesota Highway Dept., University of Minnesota, Minneapolis, Minn.

MR. HORNIBROOK.—The statement made in the author's conclusion No. 2 raises an interesting question with respect to light-weight concrete made with light-weight aggregates. It is common practice to use a considerable percentage of "fines" when utilizing light-weight aggregates of the angular type, in order to obtain the desired workability. The "fines" are of course the heaviest fraction per unit volume of the light-weight aggregates. Could not air-entrainment be employed to provide workability in such concretes, with a consequent reduction in the amount of fines needed? It seems that a real and significant advantage might thus result from the replacement of the heaviest fraction of the aggregate with the lightest possible aggregate fraction, that is, air bubbles. Certainly it is evident from Fig. 4, presented by the author, that the aggregate passing a No. 100 sieve contributes little or nothing to the entrainment of air in a form helpful to workability. It is wondered if anyone has information on the use of air-entrainment in concrete made with light-weight aggregate?

MR. F. O. ANDEREGG[8] (*by letter*).—Factors affecting air entrainment in mortars and concrete, as anticipated from previous knowledge of foam production, may be expected to include:

1. The presence of agents that lower surface tension of water.
2. The presence of agents that stiffen the air-liquid interfaces.
3. The specific surface of the solids.
4. The radius of curvature of the solid particles.
5. The packing of the solids, including the boundary effects at their surfaces.
6. The consistency of the mix.

The air-entraining agent is added to provide sufficient of the first two, but these effects may be helped by the presence of various substances attached to the aggregate, such as traces of organic compounds and finely divided clays or impalpable rock dust. These solids tend to go to the interface and help materially in stabilizing the foams.

It is a matter of observation that the air bubbles attach themselves to the aggregate surfaces in order to reduce interfacial area, and so the amount entrained should be a function of the specific surface. The limiting factors in this attachment are the radius of curvature, on the one hand, and the degree of packing of the solids, on the other. A small radius, such as is found at the point of an irregular particle, does not tend to encourage attachment of the air bubbles. Also, the bubbles tend to rise from the upper surface of the particles, and from that upper part of the lower surface which depends upon the ratio of the radii of the solid particles and of the bubbles, and, which occurs, where the center of the bubbles extends beyond the edges of the grain.

When particles of many sizes are present, that is, if the grading is continuous, they may fit together so well as to exclude air bubbles. However, if the grading is a gap grading, the imprisonment of air at the surface of the larger grains should be facilitated, not only at the under side of the larger grains, but also upon their upper sides.

It was also thought that the chemical nature of the aggregate would have little if any effect; siliceous and calcareous particles of the same shape and freedom from impurities should aid entrapment of about the same amount of air. Also, the wetter the mix and the more mobile it is and the more dilute the agents, the greater the ease of escape of the air bubbles.

To secure experimental check on this

---

[8] Consulting Specialist on Building Materials, John B. Pierce Foundation of Connecticut, New Haven, Conn.

analysis, two methods of experimentation have been used. In the flask method 50 g. of solids was introduced into a 50-ml. flask. Water, with or without the air-entraining agent, was added to fill to about 40 ml. of volume and the flask was shaken vigorously for 30 sec., and water was added up to the mark. The flask was then allowed to stand for 2 min., during which part of the entrained air bubbles rose to the surface. In some systems only one or two bubbles would arise, while in one particular instance the whole neck was nearly filled with foam (accompanying Fig. 1). The foam volume was measured, and a drop or two of alcohol was added to break down the foam. More water was added to bring the level again up to the mark and the flask and contents were weighed.

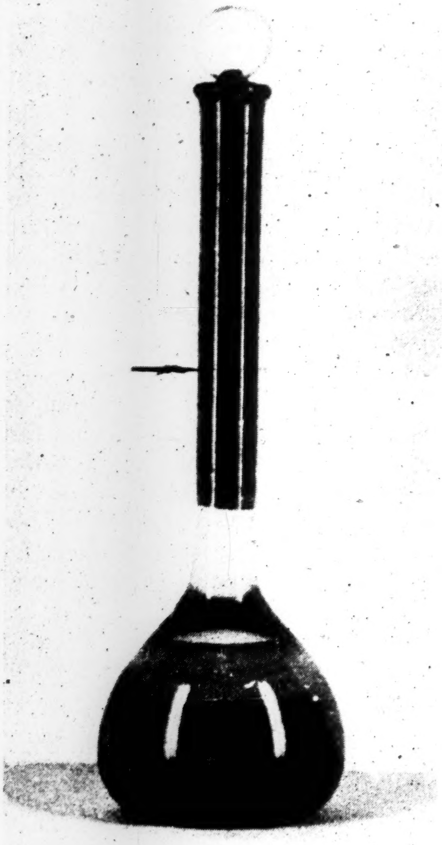


FIG. 1.—Foam Formation in the Presence of Natural Cement, where the Impalpable Dust aids in the Stabilization. The Sediment also contains a great deal of Entrapped Air.

The other, or "can," method was that recommended by the Dewey and Almy Chemical Co. for testing the effectiveness of entraining agents. A mixture of standard Ottawa sand and cement 3:1 is stirred with 15 per cent of its weight of water, and the density of the resulting mix is compared with that calculated. Where sand alone was to be studied the mixture described above by Mr. Kennedy has also been used.

The first experiments were made with Cowbay silica sand which had been ground finer in a pebble mill to supply more of the finer fractions. This material was sized with standard screens in a Ro-Tap shaker, and was tested by the flask method. Foams of 3- to 8-ml. volume formed at the top of the flask and on breaking them with alcohol, the presence of appreciable amounts of impalpable dust was noted at the interfaces. When the sand fractions were washed until free of this dust, the foaming was greatly reduced. The Dewey and Almy Darex was used as air entraining agent.

TABLE II.—AIR ENTRAINMENT BY AGGREGATE FRACTIONS, VOLUME PER CENT. FLASK METHOD.

Aggregate	Darex, Per cent[a]	16 mesh	30 mesh	50 mesh	100 mesh	200 mesh	−200 mesh	325 mesh	−325 mesh
Cowbay unwashed	none	0.03	0.1	0.4	1.0	3.5	11.7	6.2	14.2
	0.003	0.1	0.2	0.6	1.1	7.7	15.2	....	....
	0.008	1.4	...	3.8	4.6	16.8	16.3	14.1	31.3
washed	0.008	0.7	0.7	0.6	0.6	2.6	14.3	....	....
unwashed	0.012	...	3.9	4.2	5.2	22.9	18.5	....	....
Dolomite unwashed	0.008		2.3	3.3	8.3	10.2	6.7	16.8	12.8
washed	0.008	..	3.8	4.0	5.7	12.9	9.8	...	
Traprock, unwashed	0.008	3.9	4.2	4.6	5.3	12.2	4.1	..	
Scituate, unwashed	none	..		...	...	....	....	12.1	19.1

[a] Darex added, per cent based on weight of the sand.

In these experiments the amount of air entrapped depended upon the amount of Darex added, the size of the given fraction, and the presence of impalpable dust. In all cases the fraction retained on a No. 200 screen entrapped more air than larger sizes.

The effect of cement was studied next, using both cement alone, 17 g. with and without 0.03 per cent Darex, and when admixed with 50 g. washed whole Cowbay sand. The amount of air entrapped by 50 g. whole sand alone with the given amount of Darex was 0.11 ml., and 0.02 ml. in the absence of Darex.

TABLE III.—VOLUME OF AIR ENTRAINED BY CEMENTS AND BY CEMENT-AGGREGATE MIXES.

By 17-g. Cement Only			By 17-g. Cement, 50-g. Washed Cowbay Sand			
			Water		Darex	
Cement	Water, ml.	Darex, per cent	ml.	per cent by volume	ml.	per cent by volume
Type I Portland	0.24	0.37	0.45	2.5	1.71	9.4
High Early Portland	0.20	0.50	0.75	4.1	2.62	14.4
Vinsol Portland	0.16	0.87	0.93	5.1	1.92	10.6
Natural cement	0.28	0.63	2.29[a]	12.6	2.77	15.2
Hydraulic Lime	0.33	0.41	0.78	4.3	1.56	8.6

[a] Photograph reproduced in Fig. 1.

The volume of the air entrapped by the cement-sand mixes is greater than that held by the same amounts of these materials by themselves. This may well be the result of a condition at the boundary of the larger sand grains, where the cement does not pack as well as by itself. Also, the cement should help hold some air bubbles on the upper surface of the sand grains.

The natural cement was characterized by a large amount of impalpable dust which went to the air-liquid interfaces, aiding greatly in froth formation as shown in Fig. 1.

Experiments with the Dewey and Almy "can" method have yielded some results of the effect of the consistency on air entrapment, as follows:

TABLE IV.—AIR ENTRAPMENT WITH WATER ONLY.

By Unwashed Dolomite, Fraction on No. 100-sieve

Water-solids ratio, per cent	24.0	20.0	16.0
Air entrapped, volume per cent	17.1	18.3	23.9
Consistency	sl. wet	good	stiff

By 3 Washed, Whole Cowbay Sand : 1 Cement

Water-solids ratio, per cent by weight	25.0	21.7	18.3	15.0	13.3	11.7
Air entrapped, volume per cent	7.2	8.5	8.1	7.8	10.0	12.8
Consistency	very wet	quite wet	wet	sl. wet	very sl. wet	very good

By 3 Unwashed, Whole Cowbay Sand : 1 Cement

Water-solids ratio, per cent by weight	25.0	21.7	18.3	15.0	13.3	11.7
Air entrapped, volume per cent	5.1	6.5	7.7	8.7	13.3	13.8
Consistency	very wet	quite wet	wet	sl. wet	very sl. wet	very good

The wetter the mix, the less the entrainment of air.

In Table V results are given for different aggregate fractions with and without cement, and all made up to the

TABLE V—AIR ENTRAINMENT BY PLASTIC MIXES. VOLUME PER CENT

	Whole	16 mesh	30 mesh	50 mesh	100 mesh	200 mesh	−200 mesh	325 mesh	−325 mesh
225 Washed Cowbay Sand:75 Cement:45 Water									
Water only	4.1	1.4	6.2	14.3	23.7	32.3	37.1	...	...
Darex, 0.03 per cent on the cement	5.5	5.6	8.5	11.3	21.6	29.9	35.8	...	...
225 Unwashed Cowbay Sand:75 Cement:45 Water									
Water only	...	6.2	7.7	13.4	21.0	33.8	40.0	36.5	27.6
Darex, 0.03 per cent on the cement	...	6.3	8.2	13.5	19.3	32.9	36.8	...	...
250 Washed Cowbay Sand:60 Water									
Water only	...	...	...	...	19.4	18.7	...	...	...
Darex, 0.008 per cent on sand	...	...	...	...	22.6	25.0	...	...	...
250 Ottawa Sand:60 Water									
Water only	4.8	...	1.9	...	13.3	17.1	...	...	...
Darex, 0.008 per cent on sand	7.3	...	5.7	...	13.6	20.2	...	...	...
250 Dolomite:25 Cement:45 Water									
Water only	...	...	...	...	...	...	...	12.5	33.4

"very good" consistency, which means one having a very good "plasticity."

It was observed that the presence of the agent resulted in definite improvement in plasticity, while maximum apparent plasticity was reached with the fraction retained on a No. 100 sieve, after passing a No. 50 sieve. The order of magnitude of included air was also determined by making cubes from the mixtures and weighing. It checked the above values, allowing for the reduction in air content due to the working necessary for molding the specimens. At this consistency the agent helped the entrapping action for the whole sand and for the coarser fractions, but seemed to have less effect with the finer particles, probably because of the difficulty of washing all the impalpable dust from the latter.

The results of these experiments seem to bear out the initial analysis of the problem. In addition, no significant difference between silica and dolomite has become apparent.

MR. KENNEDY (*author's closure, by letter*).—While air-entraining concretes are unquestionably more impermeable than corresponding concretes in the absence of air-entraining agents, yet they are permeable to a minor degree under atmospheric pressure—at least to the extent of saturating the outer layer of a concrete surface. The remaining air voids relieve the pressure produced by freezing as shown in Fig. 6. It is apparent that if it were possible thoroughly to saturate a concrete containing entrained air, just prior to freezing, the concrete would show little resistance to disruption.

Concretes containing controlled amounts of total entrained air—3 to 5 per cent—will produce an increase in resistance to freezing and thawing ample for good performance in the field, particularly when such concrete mixes are redesigned to prevent a lower cement factor.

Where Mr. Anderegg seems in apparent disagreement with the results of my paper, particularly in the sand fractions smaller than No. 100 sieve, it is suggested that excessive stiffness of the mix masked the true measurement of entrained air. Mr. Anderegg's observation generally seems in substantial agreement with the findings in the original paper:

> "It was observed that the presence of the agent resulted in definite improvement in plasticity, while maximum apparent plasticity was reached with the fraction retained on a No. 100 sieve, after pasing a No. 50 sieve."

Because of the action of air-entraining agents on the fine aggregate (at least those studied within the scope of this investigation), it seems reasonable to believe that great improvements can be made in the manufacture of light-weight concretes with light-weight aggregates where a substitution of the heavier sand particles may be made with entrained air. It also seems reasonable that the No. 100 sieve sand fraction might even be eliminated from a concrete mix when air-entraining agents are used, without in any way harming the workability properties of the fresh concrete.

PRECISION INDICES FOR COMPRESSION TESTS OF COMPANION CONCRETE CYLINDERS

By S. P. Wing,[1] Walter H. Price,[1] and Clemeunt T. Douglass[1]

Synopsis

Representative research and field laboratories are found to mold and test companion 6 by 12-in. concrete cylinders of 4300 psi. average 28-day strength, with a precision equivalent to a coefficient of variation of 3.4 per cent. Modifications of this coefficient for tests of concrete having different strengths or utilizing different size test cylinders are given. The small variation between companion cylinders, as compared to the variations of the same number of cylinders taken from different batches, suggests that a better utilization of a limited number of tests can be made if, except for special conditions, the practice of testing companion cylinders from a single batch is abandoned.

Application of the precision coefficient to the analysis of unexplained strength variations between cylinders cured in a fog room is given. It is shown that, even in such a room, curing at different locations may cause maximum strength variations of the order of 8 per cent.

Methods for the economic determination of the number of tests required to control the uniformity of concrete on the job or for research purposes are discussed in the last section of the A.S.T.M. Report on Significance of Tests of Petroleum Products.[2] The authors of that report closed their discussion regretting that they could not make specific recommendations, because they lacked data on the precision constants. The present paper provides these values for the compression testing of companion concrete cylinders based on data from 20 widely distributed laboratories and covering 2500 batches of concrete.

Precision Index:

The most useful measure of precision, or the ability to reproduce results, is the standard deviation. This index is approximately that particular deviation plus and minus from the average which includes two thirds the total number of observations, providing a large number of observations have been made. It is likewise approximately equal to five fourths the average or mean deviation. Expressed as a per cent of the mean, it is called the coefficient of variation. Several methods for accurately computing the standard deviation are given in the Society's Manual on Presentation of Data,[3] together with certain corrections needed to convert values determined from a small number of tests to those applicable to a large number. Although the application of the correction makes the result an estimate, such corrections make it possible to compare coefficients from series of an unequal number of observations on a uniform basis. Corrections have been applied in the present paper, and, although the results should strictly be called "estimated standard deviations," the adjective is dropped.

---

[1] Engineers, U. S. Bureau of Reclamation, Denver, Colo.

[2] Report on Significance of Tests of Concrete and Concrete Aggregates (1935).

[3] A.S.T.M. Manual on Presentation of Data, 1940 edition; corrections from Table I, p. 50.

Within-Batch Coefficient:

The most uniform compression test cylinders made by a laboratory are companion cylinders from a single batch cured side by side. If from each batch the lowest test strength be subtracted from the highest, and several (30 to 100) such differences, obtained from different batches, be averaged, the number of companion cylinders per batch being the same, the average *range* thus obtained provides an easy method of computing the standard deviation of companion cylinders. In this paper such an average range in pounds per square inch, converted into a per cent by dividing by the series mean, and divided by 1.13 if two, or by 1.69 if three companion cylinders are tested per batch,[4] is called the within-batch coefficient V_{WB} (estimated coefficient of variation for companion cylinders). In a single index it measures the ability of a laboratory to mold, compact, cap, cure, and test concrete cylinders taken from the same batch in a uniform manner, making possible quantitative comparisons of technique of different laboratories. The precision of test technique does not, of course, measure that other important factor in concrete testing, interbatch precision, or the ability to manufacture and test successive batches in a manner such that successive results are uniform. Discussion of variations in interbatch precision is beyond the scope of this paper.

Controlled Tests:

Any series of observations whose fluctuations from the average follow those expected from the laws of probability is said to be under statistical control. For such a series, "if not more than 1 out of 35 successive points or not more than 2 out of 100 fall outside the $\pm 3\sigma$ (three times the standard deviation) control limits, a high degree of control may ordinarily be assumed for that period."[5] If as many as 5 in a 100 fall outside the same limits, poor control is indicated.[6]

Any observation falling outside the $\pm 3\sigma$ control limits is called highly significant in that there are high odds (370:1) against its occurring by chance in a controlled test series, and, when it does occur, it is usually practical to determine the cause. If it lies, however, only outside the 2σ limits (21:1), its variation is spoken of as being significant, and there is less likelihood of finding the cause. Smaller variations rarely are worth investigation. It is to be noted that the choice of these particular limits is purely conventional, their utility being based on practical experience. For this paper the coefficient of variation is used interchangeably with the standard deviation.[7]

Survey of Within-Batch Coefficients:

An exploratory survey of the present precision of testing companion 6 by 12-in. cylinders is tabulated in Table I, the series being numbered consecutively The series, contributed by 20 different laboratories,[8] are arranged in three groups. The first represents tests made by different operators and with different

---

[4] A.S.T.M. Manual, *loc. cit.*, p. 50, lists these under column d_2.

[5] A.S.A. Z1.3-1942, Control Chart Method of Controlling Quality during Production (American War Standard).

[6] See A.S.T.M. Manual (*loc. cit.*), p. 27.

[7] There are objections to the general substitution of the coefficient of variation for the standard deviation, but these are not important for the purpose of the presen paper.

[8] The variety of organizations represented may be noted in acknowledgments at the end of the paper.

TABLE I.—RELATION BETWEEN WITHIN-BATCH AND BATCH-TO-BATCH COEFFICIENTS OF VARIATION.

Series	Group	Standard Deviation, Within Batch, psi.	Coefficient of Variation, per cent					Number of Batches	Cylinders per Batch	Total Number of Cylinders	28-day Mean Strength, psi.	Water-Cement Ratio		Period Sampled, months	Capping	Max. Size Aggregate, in.	Type of Curing
			Within Batch V_{WB} ± Standard Deviation	Interbatch V_{IB}*	Batch to Batch, V_{BB}*	Batch Means, V_{BM}*	Outside Control Limits, V_{WB}					Mean	Range				
No. 1	Different operators	284	6.07 ± 1.1					9	3	27	4679			0.5	Sulfur	1½	Fog
No. 2		102	2.92 ± 0.4					12	3	36	3495			0.5	Sulfur	1½	Fog
No. 3		32	0.74 ± 0.1	3.22	3.31	3.28	6.7	15	3	45	4320	0.567		1	Shot	1½	Fog
No. 4		162	3.80 ± 0.4					30	3	90	4274			0.5	Sulfur	1½	Fog
No. 5		150	3.69 ± 0.3					36	3	108	4077			0.5	Sulfur	1½	Fog
No. 6		115	3.00 ± 0.2	7.6	8.2	7.9	0.6	176	3	528	3840			22	Sulfur	1½	Fog
No. 7		169	3.77 ± 0.2				0	135	3	405	4477			120	Sulfur	1½	Fog
No. 8	Research	182	3.47 ± 0.6					19	6	114	5247				Plaster Paris	2	Fog
No. 9		122	3.10 ± 0.5				0	24	2	48	3940			0.5			
No. 10		251	6.20 ± 0.7	8.1	10.2	9.2		48	2	96	4050		0.35–0.68	2	Sulfur	1½	Fog
No. 11		128	2.32 ± 0.1					13	16	208	5500			0.3	Sulfur	1½	Fog
No. 12[a]		169	3.77 ± 0.2				0	135	3	405	4477			120	Sulfur	1½	Fog
No. 13		53	2.20 ± 0.1					168	3	504	2420			0.5	Sulfur	1½	Fog
No. 14	Control	88	2.57 ± 0.6					9	2	18	3440			5	Shot	1½	Water
No. 15		150	3.93 ± 0.7				0	18	2	36	3810				Sulfur compound	1½	Fog
No. 16		196	2.84 ± 0.4	2.76	3.96	3.41	4.0	25	2	50	6900	0.408	0.38–0.44	3	Sulfur compound	⅜	Water
No. 17[b]		106	2.94 ± 0.4				0	28	2	56	3070				Sand-cement mortar	1½	Fog
No. 18		136	4.90 ± 0.7	13.7	14.8	14.35	3.3	30	2	60	2770	0.75		24	Sulfur	1½	Fog
No. 19		45	1.53 ± 0.2	10.0	10.2	10.1	3.3	30	3	90	2980				Sulfur	1½	Fog
No. 20		259	4.73 ± 0.5	13.5	14.3	13.9	7.5	53	2	106	5470	0.423	0.31–0.49	4	Sulfur compound	⅜	Sand
No. 21[c]		263	4.70 ± 0.5	5.56	7.21	6.48	5.5	55	2	110	5600	0.456	0.43–0.48	3	Sulfur compound	⅜	Water
No. 22		54	0.88 ± 0.1	4.24	4.34	4.29	1.6	61	2	122	6160	0.438	0.43–0.44	3	Sulfur compound	⅜	Fog
No. 23		119	1.93 ± 0.2	4.99	5.35	5.17	3.4	58	2	116	6170	0.396	0.35–0.45	5	Sulfur compound	⅜	Fog
No. 24		276	4.70 ± 0.4	4.56	6.54	5.64	1.3	76	2	152	5870	0.492	0.46–0.51	6	Sand-cement mortar	⅜	Fog
No. 25[c]		152	4.71 ± 0.4	19.4	20.0	19.7	2.7	74	2	158	3230	0.514	0.45–0.60	2	Sulfur	1½	Fog
No. 26[d]		176	3.94 ± 0.3	11.0	11.7	11.3	1.0	100	2	200	4480	0.67		4	Cement	1½	Fog
No. 27[c]		131	3.68 ± 0.2	22.6	23.0	22.8	3.0	151	2	302	3550				Sulfur	1½	Water
No. 28[c]		142	3.07 ± 0.2	11.9	12.3	12.1	2.6	156	2	312	4640		0.35–0.55	6	Sulfur	1, 1½	Water
No. 29		63	2.47 ± 0.1	17.3	17.4	17.4	1.2	85	3	255	2560	0.715	0.63–0.81	15	Shot	1½	Fog
No. 30		94	3.13 ± 0.1	16.2	16.6	16.4	2.8	323	2	646	3020	0.59	0.49–0.66	24	Sulfur	1½	Fog
No. 31		169	3.38 ± 0.1				0	312	2	624	5000			39	Shot	1½	Fog
	Average	146	3.39	10.39	12.48	10.79	2.97	2464[e]		6027[e]	4310						

[a] Same as No. 7.
[b] 7-, 28-, and 90-day tests combined. No significant difference between testing ages.
[c] Molded in one place, tested in another.
[d] 6 by 12 and 8 by 16 cylinder tests pooled.
[e] Total.
* These coefficients computed from data but may well not be typical.

mixes, the data coming from a single laboratory; the second, tests from different research laboratories; and the third, routine tests made in the field for job control.

The precision coefficients for companion cylinders are shown in the third and fourth columns of Table I, expressed as standard deviations and coefficients of variation V_{WB}. To the latter has been added its own standard deviation[9] as a measure of its reliability.

Column 6 gives the coefficient of variation for cylinders coming from different batches V_{BB} for comparison with the within-batch coefficient. The difference between the two coefficients measures interbatch variation V_{IB}, or variation in the strengths of succeeding batches due to inadvertent changes in water-cement ratio, fineness of cement, curing conditions, etc., and its magnitude is tabulated in column 5. It will be noted that the subtraction is not arithmetic, but according to the formula $V_{IB} = \sqrt{V_{BB}^2 - V_{WB}^2}$, the equation applicable for combining variations due to independent causes. Column 7 gives the coefficients of variation of the strength of the batch means for each series.

A comparison of these coefficients indicates that whereas the within-batch coefficient has the low average value of 3.39 per cent, with a limited range of values, the batch-to-batch coefficient for cylinders from different batches ranges from 3 to 20 per cent, and the same is true of the interbatch and batch mean coefficients.

Evidently the strength of concrete from different batches fluctuates far more widely than do the strengths of companion cylinders, and the variations between the latter provide little indication of the variation to be expected between successive batches, though they are of the same mix, and may even be of laboratory manufacture.

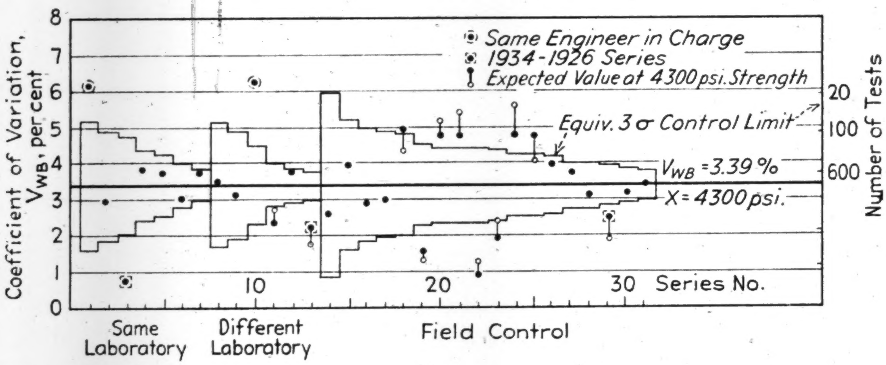


FIG. 1.—Precision Indices for Compression Tests of Companion 6 by 12-in. Cylinders—V_{WB}.

Column 8 provides an index of the constancy of the test technique over the periods covered by each test series by tabulating the number of ranges per hundred batches falling outside the + 3σ control limits. That most laboratories maintain constant technique is indicated. Series 6 and 7, covering tests over a 2- and 10-yr. period have only 0.6 and 0 ranges per hundred outside the limits, and only 3 of the 21 series surpass 5 per 100, the limit at which lack of constancy of technique is indicated.

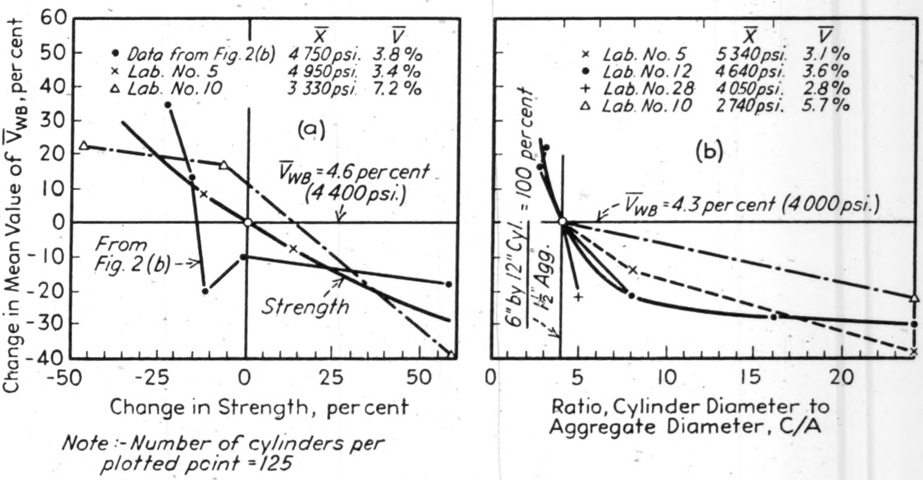
---

[9] The standard deviation of a coefficient of variation determined from the ranges of *m* batches of *n* samples each is approximated by the formula $\frac{\overline{R}}{d_2} \frac{D_4 - 1}{3} \frac{1}{\sqrt{m}}$ where d_2 and D_4 are given in Table I of the A.S.T.M. Manual (*loc. cit.*).

Within-Batch Coefficient Control Diagram:

The within-batch coefficients for the series of Table I are plotted on a control diagram in Fig. 1, utilizing the arithmetic average of all series, 3.39 per cent,[10] as its base. The 3σ control limits vary with the number of tests contained in each series, the number being approximately given by the ordinate at the right.

No significance is discernible in the groupings shown. Apparently there is an equal likelihood of obtaining a given precision for within-batch tests whether the series are made in a single laboratory, in different laboratories, or in the field. On the other hand, highly significant differences exist between the series, 14 out of 31 being outside the control limits. For eleven of these, reasonable explanations are possible. Low coefficients are found to be associated with high average strengths, and correcting for variations in strength (the open circles on the diagram), four additional series fall within the boundary lines. Small maximum aggregate size likewise is found to promote uniformity. The maximum aggregate of series Nos. 22 and 23 was $\frac{3}{8}$ in., and this factor may explain the low values of their coefficients. Uniform curing is essential to high precision; series Nos. 1 and 10 both were made in early years when uniformity of curing is open to doubt. Finally, technique of operators varies. The low coefficients found in series Nos. 3, 13, and 29 were all obtained by an operator whose test work has consistently indicated high precision and who rigidly followed specifications.



Note :- Number of cylinders per plotted point = 125

FIG. 2.—Per cent Change in V_{WB} *versus* Strength and Cylinder-Aggregate Diameter Ratio.

MODIFYING FACTORS AFFECTING COEFFICIENTS OF VARIATION

The high average precision with which tests on companion cylinders are made, the many factors causing variation which the coefficients reflect, the large number of tests required to detect significant differences between coefficients, their normal variation, and the usage to which they are put, make it impractical and unnecessary to give other than broad generalization of the factors which modify their values. For discussion, coefficients applicable to about 4000-psi. concrete with 1½-in. maximum aggregate, and tested in 6 by 12-in. cylinders, are taken as a standard.

---

[10] On some grounds, rather than an arithmetic average, an averaged weighted in accord with the square of the individual coefficients would be a more suitable average.

Coefficient versus Strength:

Figure 2(*a*), with data from three laboratories,[11] shows the relationship between the within-batch coefficient and strength, each series being plotted as a percentage of its own mean. The series from laboratory 5, a large field job, is particularly reliable, the sampling period extending over more than a year for each of two concretes of different strengths, but manufactured at the same plant. As a rough rule, the data show that a given percentage change in average strength produces 60 per cent of that change in the value of the within-batch coefficient, but in the opposite sense. Tests on 2000-psi. concrete would, therefore, be expected to have about a 30 per cent higher coefficient than 4000-psi concrete.

Coefficient versus Ratio of Cylinder Diameter to Maximum Aggregate Diameter:

Figure 2(*b*) shows the percentage change in the coefficient as a function of the cylinder diameter to the maximum aggregate diameter, more briefly referred to as the cylinder-aggregate diameter ratio *C/A*. The data, Table II, are heterogeneous and include both series of 6 by 12-in. cylinders in which different size aggregate was placed, and cylinders of different diameters and aggregate sizes, the strengths in no case being uniform, so the authors only offer it as the best information which, at present, is available. The mean curve may be used for estimating the probable coefficient where tests are made on other than 1½-in. aggregate in 6-in. cylinders. The effect of the *C/A* ratio shown reflects not only the probable greater uniformity present in a cylinder whose diameter is large with respect to the diameter of the maximum aggregate, thus being statistically more homogeneous, but also any effects due to strength and absolute area changes which normally are involved in such test series.

TABLE II.—WITHIN-BATCH COEFFICIENT RATIO OF CYLINDER VERSUS MAXIMUM AGGREGATE DIAMETERS.

Laboratory	Cement-Aggregate Diameter Ratio, *C/A*	Coefficient Variation, Within Batch, per cent	Cylinder, in.	Maximum Aggregate, in.	Mean Strength, psi.	Number of Batches and Cylinders	
						Batches	Cylinders per batc
No. 5	4	3.7	6 × 12	1½	4925	1	17
	8	3.2	6 × 12	¾	5610	2	8
	24	2.3	6 × 12	¼	5475	1	9
Mean		3.1			5340		
No. 12	2.7	4.4	8 × 16	3	4050	31	3
	3	4.6	18 × 36	6	2846	14	2
	4	3.8	6 × 12	1½	4451	119	3
	8	3.0	6 × 12	¾	4382	52	3
	16	2.7	3 × 6	3/16	7465	8	3
Mean		3.6			4640		
No. 28	4	3.0	6 × 12	1½	3330	87	2
	4	3.4	6 × 12	1½	4620	87	2
Mean		3.2			3980		
	6	2.3	6 × 12	1	3580	64	2
	6	2.7	6 × 12	1	4670	64	2
Mean		2.5			4120		
Over-all Mean		2.8			4050		
No. 10	4	6.4	6 × 12	1½	2646	80	2
	24	5.0	6 × 12	¼	2830	80	2
Mean		5.7			2740		

It has been suggested[12] that changes in the absolute area of the test cylinder should cause the coefficients to vary inversely with the diameter ratios of the cylinders, a 3-in. diameter cylinder having twice the variability of a 6-in. cylinder, on account of the effect of increased area in averaging out defects. That such effect exists was indicated in tests at laboratory No. 6. Tests of $\frac{3}{4}$-in. aggregate in 3-in. cylinders and $1\frac{1}{2}$-in. aggregate in 6-in. cylinders gave coefficients of 4.8 ± 0.3 per cent and 3.0 ± 0.2 per cent, respectively. The ratio of the two coefficients is 1.57, somewhat smaller than anticipated by this particular theory.

---

[11] The test data are referenced by a laboratory number, the same as the series numbers of Table I, meaning that the same laboratory made both series of tests.

[12] John Tucker, Jr., Discussion of Paper by S. P. Wing and A. Ruettgers, "Variations in Strengths of Portland Cements," *Proceedings*, Am. Soc. Testing Mats., Vol. 43, p. 943 (1943).

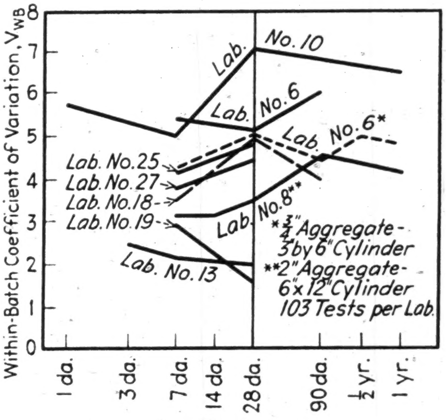


FIG. 3.—Within-Batch Coefficient of Variations *versus* Test Age.

Coefficient versus Test Age:

Figure 3 shows variations of within-batch coefficient for breaking ages of from 1 day to 1 yr.

Two principal factors are involved. Since strength increased with age, other things being equal, in accord with the data just presented the coefficients should decrease. This is true for laboratories Nos. 13 and 19 whose precision and control of testing were of a high order. Since it is more difficult to maintain constant curing over a long period than over a short one, an increase in the coefficient with breaking age should ordinarily be expected. Most series show an increase in the coefficient at breaks later than seven days. This indicates that the greater variation in strengths usually found for 7-day tests for concrete from different batches is not due to experimental difficulties, but represents real variations in the strength of the cylinders.

Confirming information on the importance of uniform curing to low within-batch coefficients was provided by check tests made on six of the test series of Table I. Duplicate companion cylinders from the same batches were shipped from the field laboratories for Governmental testing. An average increase of 50 per cent of the within-batch coefficient resulted, presumably due to inequalities of curing present during shipment.

APPLICATION OF WITHIN-BATCH COEFFICIENT

Fog-Room Control (Fig. 4):

The determination of whether a difference found between two series of tests is significant, or whether it is within the limits of experimental error, is an insistent question which continuously faces a concrete technician. Knowledge of the magnitude of the within-batch coefficient often makes an answer possible.

At laboratory No. 6, three cylinders were made weekly over a considerable period from batches of concrete made of constant materials, water-cement ratio, and slump, to determine the precision of concrete control. The three companion cylinders from each batch were cured in a 100 per cent fog room in sets on a shelf (Fig. 4(*e*)), along the north wall of the curing room, with the No. 1 cylinder always placed on the passageway and the No. 3 cylinder against the wall. The location of the sets was irregular, but they were always placed in one or another of the first eight positions at the right of the shelf. The fog spray entered as a high velocity jet at the left of the room about 4 ft. above the shelf, circulation being maintained through the air conditioner at the right. A cursory examination of sets of cylinder strengths suggested the No. 1 cylinders more often tested high than did the No. 3 cylinders.

The difference between the average strength of 176 No. 1's and 176 No. 3's was 47 psi., at an average strength level of 3840 psi. The question was whether the difference was real or a matter of chance.

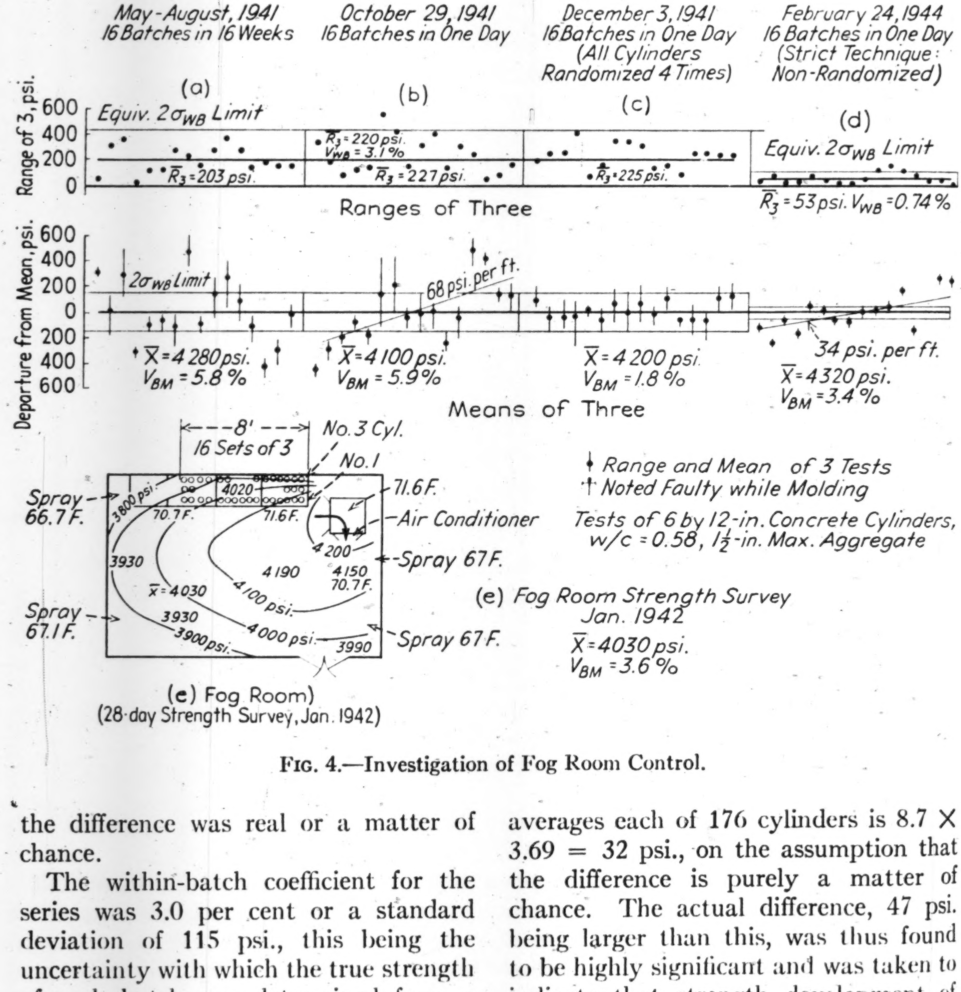


FIG. 4.—Investigation of Fog Room Control.

The within-batch coefficient for the series was 3.0 per cent or a standard deviation of 115 psi., this being the uncertainty with which the true strength of each batch was determined from a single test. The average of 176 observations, each of which is uncertain by 115 psi., is in itself uncertain with a standard deviation of $\frac{115}{(176)^{\frac{1}{2}}} = 8.7$ psi. From the A.S.T.M. Manual the average range of pairs of observations is 1.13 times the standard deviation with but one chance in 370 of getting a value either approaching zero or as high as 3.69 times the standard deviation. Thus the expected maximum difference between two averages each of 176 cylinders is 8.7 × 3.69 = 32 psi., on the assumption that the difference is purely a matter of chance. The actual difference, 47 psi. being larger than this, was thus found to be highly significant and was taken to indicate that strength development of the concrete cylinders was influenced by their location on the curing shelf.

The finding that two cylinders cured

TABLE III.—INVESTIGATION OF FOG ROOM CONTROL—STRENGTHS OF 6 BY 12-IN. CYLINDERS.

		Batch No. 1	Batch No. 2	Batch No. 3	Batch No. 4	Batch No. 5	Batch No. 6	Batch No. 7	Batch No. 8	Batch No. 9	Batch No. 10	Batch No. 11	Batch No. 12	Batch No. 13	Batch No. 14	Batch No. 15	Batch No. 16	Batch No. 17	Batch No. 18	Batch No. 19	Batch No. 20
SERIES A	Cylinder No. 1	4560	4420	4780	3960	4140	4140	4280	4670	4100	4510	4630	4210	4120	3750	4050	4300				
May 5-Aug. 18, 1941	Cylinder No. 2	4620	4100	4420	3980	4260	4260	4240	4900	4260	4230	4700	4490	4260	3930	3890	4170				
$\bar{X}$ = 4280	Cylinder No. 3	4600	4350	4510	3980	4170	4240	4000	4670	4170	4510	4320	4390	4140	3890	3960	4320				
16 different weeks	W/C	0.581	0.581	0.578	0.581	0.579	0.579	0.578	0.584	0.578	0.577	0.575	0.578	0.578	0.578	0.580	0.578				
SERIES B	Cylinder No. 1	3610	3890	3940	4030	3980	4530	4510	4120	4240	4230	3930	4100	4580	4530	4280	4090				
Oct. 29, 1941	Cylinder No. 2	3560	3820	3930	4100	3960	4240	4370	4090	4120	3840	3860	3860	4700	4490	4240	4350				
$\bar{X}$ = 4100	Cylinder No. 3	3910	3710	3860	3980	3840	3980	4090	3980	3930	4240	3800	4170	4460	4490	4210	4240				
SERIES C	Cylinder No. 1	4240	4280	4310	3900	4180	4040	4460	4020	4100	4180	4310	4160	4170	3970	4390	4430				
Dec. 3, 1941	Cylinder No. 2	4400	4170	4070	4320	4240	4220	4100	4180	4210	4100	4210	4090	4240	4210	4170	4220				
$\bar{X}$ = 4200	Cylinder No. 3	4200	4050	4110	4260	4000	4120	4220	4360	4410	4240	4380	4160	4000	4190	4340	4300				
SERIES D	Cylinder No. 1	4190	4040	4260	4160	4350	4300	4280	4240	4300	4340	4450	4560	4130	3800*	4560	4560				
Feb. 24, 1944	Cylinder No. 2	4220	4100	4260	4140	4340	4340	4270	4240	4340	4380	4300	4480	4220	3700*	4600	4560				
$\bar{X}$ = 4320	Cylinder No. 3	4190	4070	4280	4140	4410	4340	4260	4240	4340	4280	4340	4440	4180	3780*	4600	4580				
SERIES E	Cylinder No. 1	4290	3910	4220	4240	3920	3890	4080	4130	4060	4260	4520	4030	3870	3940	3810	4170	3960	3890	4270	4200
Jan. 28, 1942	Cylinder No. 2	4130	3940	3990	3870	3840	3820	3960	4310	4100	4260	4200	3990	3960	4190	3980	3920	3820	4050	4310	4360
$\bar{X}$ = 4030	Cylinder No. 3	4050	3940	3820	3730	4050	3890	4170	4190	4170	4060	4220	4150	3990	3980	3770	3920	3850	3990	4200	4400

* Batch noted faulty while molding.

GENERAL NOTES.—Mixes: 1:2.6:4.1 with graded 1½-in. maximum size aggregate; $W/C = 0.578$; vibrated into cast-iron molds; cured in 70 F., —100 per cent humidity room. Series A, one batch per week for 16 weeks; other series of 16 each made in single day.

Cement: Laboratory ground from same supply of clinker; ground to 1940 sq. cm. per g., May 1941, for series A. B, C, and E; ground to 1875 sq. cm. per g., January, 1944, for Series D.

Proportioning: Standard procedure for series A and B; cement and fine sand separated into portions by running through splitter, series C and E; sand only split in series D.

Molding: Standard except for series D in which ends were ground flat to 0.003-in. tolerance, and special attention was paid to mold leakage.

Capping: Series D shot-capped; other series, sulfur.

Curing: Series A, sets cured at different irregular shelf locations. Series B, sets on shelf in order of making; batch numbers increase from right to left. Series C, on shelf; all cylinders randomized durng curing period at 2, 4, 8, and 16 days. Series D, sets on shelf in order of making; batch numbers increase from right to left. Series E, batches Nos. 1 to 8, $\bar{X} = 4020$, sets on shelf in order of making; batches Nos. 9 and 10, $\bar{X} = 4150$, east wall under spray; batches Nos. 11 and 12, $\bar{X} = 4190$, east center, front of spray; batches Nos. 13 and 14, $\bar{X} = 3990$ southeast corner; batches Nos. 15 and 16, $\bar{X} = 3930$, west central; batches Nos. 17 and 18, $\bar{X} = 3930$, west; batches Nos. 19 and 20, $\bar{X} = 4290$ submerged in water (not included in average); all cylinders randomized at each location during curing except batches Nos. 1 to 8.

Technique: Standard: Series D was by expert operator who followed specifications rigidly.

12 in. apart had a strength difference of 1.2 per cent suggested tests to determine what effect other locations had on strength development. As opportunity offered, over a 3-yr. period five series of tests were run, the data being given in Table III and plotted in Fig. 4. In series A, a part of the longer control series, 16 sets from batches made a week apart were placed on the curing shelf in the usual hit-or-miss fashion; the batches for each of the other series were all made in a single day. For series B, the sets were placed for cure on the shelf in the order of making, starting from the right. For series C, *all cylinders were completely randomized three times* during the 28-day curing period; for series D, they were again cured in sets in the order in which they were made; and for series E, they were grouped in sets of two in different locations in the curing room. For series A, standard technique was used; for series B and C, the cement and aggregate were run through a splitter and divided into the 16 portions needed for the 16 batches. For series D, the technique of testing was improved, and the amount of fog supplied by the sprays was cut in half. Finally, series E, of 20 batches, for which the original standard technique of molding and curing cylinders was used, was divided into 10 sets of two batches each, which were placed in different locations in the curing room (see plan).

Control charts for both batch ranges and average strengths are shown at the top of Fig. 4, the 2σ control limits (21:1 *odds*) *being computed from the average range.* The magnitude and pattern of the ranges for series A, B, and C appeared to be independent of the location of the sets of cylinders on the curing shelf and the technique of within-batch testing was well controlled, only one range in 48 being outside the 2σ limit. Great improvement in technique was shown in series D where with an expert operator and attention to detail, the average range was cut in fourth. The average range in strength of three cylinders was only 53 psi., equivalent to a coefficient of variation of 0.74 per cent, truly a remarkable precision. This may be compared to a value of 3.1 per cent the grand average of the 176 batch series. Elimination of all mold leakage, cylinder ends plane to within 0.003 in., reduction of free water in the fog sprays to an amount sufficient to maintain 100 humidity with a minimum of free-water precipitation on the cylinders, splitting the sand through a sampler, and a uniform technique are believed to be the principal factors contributing to this high precision.

In contrast to the range control charts, those for averages of the different series show striking differences. Only in series C, in which all cylinders were randomized four times, were the averages kept within the prescribed control limits as determined from the within-batch coefficient. Evidently causes of variations exist affecting the strengths of cylinders from different batches which are not present in tests of sets of cylinders from a single batch. For series A, where the sets from different batches were placed at irregular locations on the curing shelf, the variation of the averages is irregular. In series B and D, where the sets were placed and remained in regular order on the shelf, the variation is regular, strengths increasing to the right at a significant rate of about 50 psi. per foot of shelf. This may be compared with the 47-psi. variation per foot previously found between the No. 1 and No. 3 cylinders.

Finally the plan of Fig. 4 shows strength contours for the curing room drawn from the tests of series E, each of the blocked figures representing the average strength of six randomized cylinders. The contours indicate an 8.0 per cent range in strength across the room. These same cylinders show a highly significant correlation between specific gravity and strength, the latter increasing 82 psi. per 0.01 unit increase in specific gravity, equivalent to a 68-psi. increase in strength for each 0.10-lb. increase in the actual weight of a cylinder. Since sets completely cured in water showed the highest strength, 4290 psi., and the highest specific gravity, a reasonable hypothesis is that the differences in specific gravity were caused by differences in absorbed water, which in turn varied with the amount of fog precipitated as water on the cylinders while curing. Differences in the wetness of the surfaces of cylinders were readily noticeable.

For randomized series C, the average gain in weight per cylinder by direct measurement during curing was 0.17 ± 0.007 lb. When the amount of spray was reduced in series D, the average gain fell to 0.04 ± 0.007 lb., but the No. 1 cylinders averaged 0.08 lb. more than the No. 3 cylinders. Since series E showed 68 psi. strength gain per 0.10 lb. weight increase, these two independent determinations may be combined to give an expected strength difference between No. 1 and No. 3 cylinders of 54 psi. This compares with the 47 psi. measured from averages of 176 sets.

Summary of Curing Room Tests:

The following tabulation gives the various coefficients of variation for these curing room tests:

	Coefficients of Variation from Curing Room Tests, per cent				
	Series A	Series B	Series C	Series D	Series E
V_{WB}	3.1	3.1	3.1	0.74	2.9
V_{IB}	5.5	5.6	0	3.40	3.0
V_{BB}*	6.3	6.4	3.1	3.50	4.4
V_{BM}**	5.8	5.9	1.8	3.40	3.6

* One cylinder per batch.
** Means of three cylinders per batch.

A comparison of the within-batch coefficient V_{WB} with the computed interbatch coefficient V_{IB} indicates that, even in laboratory work, difficulties in making successive batches identical are such as to introduce strength differences between batches as large or larger than those which exist between cylinders from the same batch.[13] Variation in the amount of water available for absorption at different locations in the curing room is found to be a major cause of such variation. This was shown by the zero value of the interbatch coefficient in series C where the cylinders were randomized while curing and was supported by data on variations in weight gain while curing. Other sources of interbatch variation were variations in cement and fine sand grading witnessed by the low values of the batch-to-batch coefficients, V_{BB}, obtained in series C, D, and E, where materials were proportioned by a splitter.

Specifications and Coefficients of Variation:

Specification and practice at present do not appear to recognize adequately the distinctions between the variation coefficients. A.S.T.M. Standard Method of Test for Compressive Strength of Concrete (C 39 - 42),[14] paragraph 17, states, "Three to five test specimens should be made on different days in investigations in which accurate comparisons are desired." Since, however, studies of curing, capping, effect of strength of cylinder size, tamping, corrosive waters, etc., can all be made by treating cylinders from the *same* batch differently, and since for this arrangement of tests the precision of testing is higher than it is if the cylinders come from different batches, the above specification clause appears to need modification.

---

[13] Report of Subcommittee VII on Strength: Report on "Cooperative Tests of Thirty-Two Portland Cements by Forty-Seven Laboratories," *Proceedings*, Am. Soc. Testing Mats., Vol. 28, Part I, p. 261 (1928). Reports on data which yield coefficients of variation for sets of 6 by 12 cylinders taken from identical batches of concrete made on different days by a given laboratory with the same cement of $V_{BB} = 8.2$ per cent, which may be compared with the average within-batch coefficient of $V_{WB} = 3.4$ per cent of the present paper.

[14] 1942 Book of A.S.T.M. Standards, Part II, p. 391.

A.S.T.M. Tentative Specifications for Ready-Mixed Concrete (C 94 – 43 T)[15] implies that a strength test shall be the average of *three* cylinders made from a composite sample of concrete taken from a single batch, but if one cylinder shows manifest evidence of improper sampling, molding, or testing, its test strength is to be excluded from the average. Considering the last clause first, the only method the authors know by which the results from such a cylinder can be excluded legitimately from the average without the possibility of argument, and assuming that prior to the break the record run sheets do not carry notes evidencing suspected faults,[16] is by reference to within-batch coefficients as determined on the job. Using the value 3.4 per cent as given by this paper as typical, a range of strength from three cylinders greater than 15 per cent ($4.4 \times 3.4 = 15$ per cent) of the job strength is outside the 3σ control limits and could be accepted as presumptive evidence that one of the cylinders of the test was defective.

Considering the first clause, the small variation of companion cylinders made from a composite sample (within-batch coefficient), as compared to the much larger variation of the strengths of successive batches (interbatch coefficient), makes the requirement for tests of three companion cylinders uneconomical and of doubtful utility. The following tabulation illustrates the negligible increase in precisions gained by testing two rather than a single cylinder per batch, and the advantages of testing a greater number of batches, using data drawn from both the laboratory and the field.

	Research Laboratory Coefficients, per cent	Field Control Coefficients, per cent
GIVEN DATA		
V_{WB} Within-batch coefficient	±3.0	±2.5
V_{IB} Interbatch coefficient	4.0	5.5
RESULTANT UNCERTAINTY AS TO PROBABLE AVERAGE STRENGTH OF CONCRETE AFTER MAKING TESTS		
Test of single batch with 1 cylinder	5.0	6.1
Test of single batch with 2 cylinders	4.5	5.8
Test of two batches with 1 cylinder each	3.5	4.3

It can be seen that doubling the number of tests per batch increased the precision by but 7 per cent; on the other hand, by doubling the number of batches tested by single cylinders, the precision was increased by 30 per cent. Most field concrete tests have greater interbatch variation than shown in the above tabulation, so the advantages of testing more batches with single cylinders each is greater than that indicated.

Finally data from actual test records of two field jobs should be convincing as to the negligible benefit derived through testing batches in duplicate. Six cards, each containing companion cylinder strengths, were chosen at random from a 3-week record period, a part of that of test series No. 29 of Table I. The average strength of the six No. 1 and six No. 2 companion cylinders proved to be identical, 2402 psi. Twelve cards sampled from a 2-month record gave strength averages of 2404 and 2406 psi.; from 29 cards over a 6-month record, the values were 2174 and 2184 psi. On another job, from 10 cards representing batches made within a 2-day interval, the averages were 6256 and 6239 psi. While the differences in these sets of averages are less than could be expected from most jobs, the precision of within-batch testing being above average, it is thought that if readers make similar computations from their own records, they will find the differences of these averages surprisingly small. However it must be remembered that close agreement of average strengths of sets of *companion* cylinders is no indication whatever of the differences to be expected between pairs of averages made up of cylinders from different batches, even though the batches come from the same record period. In all of the above examples, the interbatch variation during the chosen record periods was of the order of 10 per cent. With interbatch variation of this magnitude, the expected difference in averages of sets of cylinders from different batches is expected to be measured in hundreds of pounds.

---

[15] 1943 Supplement to Book of A.S.T.M. Standards, Part II, p. 105.

[16] This type of note applied to Batch 14, Fig. 4(*d*).

Economic Considerations:

Concrete research is costly and the value of high precision in such work is not always realized. The relative number of cylinders required to reach a specified precision varies as to the square of the coefficient of variation. The average laboratory makes "within batch" tests with a precision given by a coefficient of variation of 3.4 per cent. If it can improve its technique to the 2 per cent level which this survey indicates is normally being attained by some operators, it can reduce the number of cylinders needed for a given test program by two thirds, for the researches for which within-batch cylinders are suitable.

Field control in this country has yearly required the testing by companion cylinders of many thousands of batches of concrete. Since the cost of sampling, testing, and computing results from 6 by 12-in. test cylinders may be placed at $4.00 for a pair, and at $2.50 if but one cylinder is tested, a change of specifications to permit the use of but one cylinder per batch sampled has the possibility of saving many thousands of dollars to the concrete industry annually, with little loss in precision. Alternatively, by changing the specifications to require that the number of cylinders tested should remain the same as at present but that each should come from different batches, a material increase in precision may be obtained at no increase in cost.

CONCLUSIONS AND ACKNOWLEDGMENTS

Conclusions have been given in the synopsis and body of the paper.

The authors wish to thank the following organizations whose cooperation have made this paper possible: Bureau of Reclamation Laboratories; Bureau of Standards, Denver office; City of New York, Department of Public Works; Colorado State Highway Department; Illinois Division of Highways; War Department, Little Rock Engineer District; Pierce Testing Laboratories; Portland Cement Association; Tennessee Valley Authority; and the U. S. Maritime Commission. The concrete laboratories of the Bureau of Reclamation are under the supervision of R. F. Blanks. All engineering research and design are under the direction of J. L. Savage, Chief Designing Engineer. S. O. Harper is Chief Engineer, and H. W. Bashore is Commissioner of the Bureau of Reclamation.

DISCUSSION

Mr. H. W. Leavitt[1] **and Mr. H. A. Pratt**[1] (*by letter*).—Once again the engineers at the Denver Laboratory have presented a classic in the field of concrete data analysis. Concrete technicians have long awaited basic data and *precision indices* (standard deviations, and coefficients of variation) to use in sizing up the accuracy and the predictive value of their own particular projects. They individually want to know whether their particular performance is good or bad. The amount of work required to comb out all of the relationships involved in a large mass of data on concrete cylinders is incomprehensible to anyone who has not actually made such a statistical study. In order for *indices* to be of high value, however, they must be derived from an adequate population (number of test results). Even the casual reader of this paper will be impressed by the quantity of data (6027 cylinders) upon which this study was based.

Former studies in this field have been generally limited to smaller (mortar) specimens. Reference to Table II of the writers' 1939 paper[2] will show that the values of v (coefficient of variation) for "Variation Among All Individuals" were found to be always appreciably larger than v for "Variation Within Daily Batches." The same relationship is indicated in Table III of this same paper. Messrs. Wing, Price, and Douglass have now established a similar relationship for concrete cylinders. This is shown by the values of the several coefficients of variation given in Table I. It will be seen that in every case cited (except two) the values of V_{WB} are substantially less than the corresponding values for V_{IB}, V_{BB}, and V_{BM}. The averages of these coefficients are available for comparison with the individual data of other concrete technicians. For example, the Maine Technology Experiment Station has obtained, on a small number of batches, a $V_{WB} = 7.5$, which is comparatively bad when placed beside the authors' value of $V_{WB} = 3.4$. This is a disappointing but stimulating comparison. Evidently much improvement is possible in our laboratory and we await with great interest the presentation of the results of other laboratories.

Statistical material presented in papers of this character will provide valuable indices to be studied and incorporated in future symposiums on the significance of tests of concrete and concrete aggregates. The sampling of concrete in the future may well be guided by the principles set forth by the authors of this paper.

Mr. Duff A. Abrams[3] (*by letter*).—This paper is the latest in a series that has one thing in common—variation in tests of concrete made by the U. S. Bureau of Reclamation. Earlier papers and discussions are listed in Table 1. Attention is called to two features:

Discussions before the American Concrete Institute that were dropped by

---

[1] Secretary and Assistant Engineer, respectively, Maine Technology Experiment Station, University of Maine, Orono, Me.

[2] H. W. Leavitt and H. A. Pratt, "Statistical Analysis of Compression Tests on Mortar Cylinders, Cubes, and Prisms," *Proceedings*, Am. Soc. Testing Mats., Vol. 39, p. 851 (1939).

[3] Consulting Engineer, New York, N. Y.

U.S.B.R. writers in 1939 were resumed before the A.S.T.M. in 1943.

The U.S.B.R. has been represented by ten different authors.

The writer's first discussion of a paper on "Mixer Efficiency or Mortar-Mix Tests," by O. G. Patch, in the *Journal* of the American Concrete Institute, June 1939, commented on the unique method used in computing mixer efficiency from two mortar samples or three concrete cylinders at Grand Coulee Dam:

> "There are well-recognized methods of indicating the variation of a set of observations, such as mean variation, probable error or standard deviation. The author discarded all these for a method which has the following novel features:
>
> "(*a*) No balancing of positive against negative errors,
>
> "(*b*) The *middle* value (nearest to the proper one) is given no weight, except to establish a sequence,
>
> "(*c*) No use was made of the average value,
>
> "(*d*) What is termed 'variation' should be 'spread,'
>
> "(*e*) The spread appears to be 3 to 10 times the mean variation. . . ."

Both Mr. Patch and Arthur Ruettgers presented vigorous arguments to show that their method of computation was sound, but the writer's method would not work. Someone must have decided there were usable ideas here for the next revised edition of the U.S.B.R. "Concrete Manual," January, 1941, contained three innovations as compared with the editions of 1936, 1938, 1939:

A 16-page essay on "Presentation and Significance of Test Data,"

An "alternate" method of computing mixer efficiency, the usual prelude to dropping a method. (The Patch test was entirely dropped before the 1942 "Manual" appeared.)

The alternate method of handling mixer test data was that suggested by the writer (but without acknowledgment).

Experience thus far enables one to recognize the "formula" developed by the U.S.B.R. for dealing with the writer's criticisms:

TABLE 1.—PAPERS AND DISCUSSIONS ON VARIATION OF U.S.B.R. TESTS OF CONCRETE.

Reference Number	Paper or Discussion	Date Published
	PUBLISHED IN *Journal* OF AMERICAN CONCRETE INSTITUTE	
1*a*	Paper by O. G. Patch, "Mixer Efficiency or Mortar-Mix Tests"	Jan. 1939
b	Discussion by Duff A. Abrams	June 1939
2*a*	Rebuttals by Patch and Arthur Ruettgers	June 1939
b	Second discussion by Abrams	Sept. 1939
3*a*	Closure by Patch	Sept. 1939
4*a*	Paper by Blanks, Vidal, Price and Russell, "The Properties of Concrete Mixes"	April 1940
b	Discussion submitted by Abrams.	Not published
	PUBLISHED IN A.S.T.M. *Proceedings*	
5*a*	Paper by S. P. Wing and Arthur Ruettgers, "Variations in Strength of Portland Cements Conforming to the Same Specifications and the Relation of Such Variations to Concrete Control"	1943, p. 917
b	Discussion by Abrams	1943, p. 946
6*a*	Closure by Wing and Ruettgers	1943, p. 969
7*a*	Paper by S. P. Wing, Valens Jones, and R. E. Kennedy, "Simplified Test for Evaluating the Effectiveness of Concrete Mixers"	1943, p. 1001
b	Discussion by Abrams	1943, p. 1014
8*a*	Closure by Wing, Jones and Kennedy	1943, p. 1058

(*a*) Ignore criticisms, or reject them as "irrelevant and inaccurate or unreasonable statements,"

(*b*) Make a few special tests,

(*c*) Choose a new group of authors,

(*d*) Publish a new paper under a different title, covering the same topics; restate the original claims, withhold pertinent data, do not mention previously ignored or rejected criticisms, (*e*) Surreptitiously adopt the ignored or rejected criticisms.

The present paper follows the formula exactly through step (*d*). Specifically it is an attempt to refute certain conclusions in the writer's discussions of two A.S.T.M. papers of 1943. In a discussion of Wing and Ruettgers' paper it was pointed out that:

> "The value $v = 5.5$ per cent was the within-batch error and 7.5 per cent the all-test error of carefully made laboratory tests of concrete,
>
> "The absurdly low coefficients of variation of field tests of concrete, 2.9 per cent, resulted from twinning of the duplicate tests at Grand Coulee Dam,
>
> "A proper evaluation of test errors will make it necessary to discard most of the conclusions stated by the authors."

The writer's discussion of Wing, Jones, and Kennedy's paper showed that from the standpoint of variations, many of the conclusions on concrete mixers were not supported by the tests.

SUMMARY AND CONCLUSIONS

1. Many of the principal series of the paper were "selected." Forty-two U.S.B.R. series that were omitted from the paper are listed; most of those on which we have information gave coefficients of variation higher than the average of the paper.

2. What the authors report as within-batch variation are only the slight differences found in a composite sample from which variation had already been eliminated. The only U.S.B.R. tests known to show within-batch variations were omitted from the paper. They gave a *variance* for laboratory tests 3 times and for job tests 10½ times that reported in the paper.

3. After rejecting 3 tests, series 3, by an operator famous for low variations, was used as representative of "20 widely distributed" "representative research and field laboratories."

4. The within-batch coefficient of series 3 (or D), the only one in Table I for which data were given, was 0.74 per cent. This "truly remarkable precision" was attributed to "improved technique and attention to detail." It was, in fact, due to "twinning" of tests. When partly corrected for "twinning," the coefficient became 3.7 per cent. As *variance* this is $(3.7/0.74)^2 = 25$ times that given in the paper.

5. The authors point to the A.S.T.M. Manual on Presentation of Data as their authority on statistics, but many of its teachings were disregarded. Unscientific sampling of concrete places many of the data in the paper outside the range of statistical methods.

6. The writer disagrees with the authors' recommendations on number of strength tests in the inspection of ready-mixed concrete.

7. The "fog-room survey" contradicts every conclusion drawn from it by the authors.

8. The effects that the authors attributed to size of aggregate should have been charged to strength of concrete.

9. The authors appear to have attempted to gerrymander discussions to exclude consideration of all-tests variations, although the paper gave data on, and repeatedly considered, this subject.

10. The paper confirmed relations pointed out by the writer last year and furnished the basis of a more complete strength-variation law:

> "The coefficient of variation of concrete cylinders tested at 28 days increases as a logarithmic function of the number of tests, and for a given number of tests, varies inversely as the strength of the concrete."

11. Selection of series, tests made on composite samples of concrete (from which variation had already been elim-

inated) and "twinning" of strengths in cylinder tests, make the conclusions of the paper, without exception, unwarranted and misleading.

The authors are requested to furnish missing data on mixing and sampling of the concrete, on twinning of tests, and on tests rejected in the 30 series in Table I.

PAPER BASED ON SELECTED TESTS

In a discussion of Wing and Ruettgers' paper (Proc. 1943, p. 1014) the writer characterized as "absurdly low" a within-batch coefficient of 2.9 per cent obtained at Grand Coulee Dam during July 1937. Six U.S.B.R. laboratory series were cited that gave average coefficients:

Based on 2 tests............ $v = 5.5$ per cent
Based on all tests........... $v = 7.3$ per cent

Messrs. Wing and Ruettgers attempted to refute the writer's conclusion by discrediting the U.S.B.R. data on which it was based. This paper restates essentially the same "absurdly low" figure:

> "Representative research and field laboratories are found to mold and test companion 6 by 12-in. concrete cylinders... with a precision equivalent to a coefficient of variation of 3.4 per cent."

A little study showed that the low values were due to:

1. Selection of test series,
2. Reporting composite-sample variation as "within-batch" variation,
3. "Twinning" of strengths in cylinder tests.

Evidences of the "selection of series" will be given first.

(*a*) Concrete literature is filled with series that were not used in Table I, but here we consider only U.S.B.R. tests that were omitted. A search of a few minutes through papers and reports that happened to be at hand enabled the writer to compile the accompanying Table 2, which lists 42 U.S.B.R. series,

TABLE 2.—CONCRETE TESTS BY U.S.B.R. OMITTED FROM TABLE I.

Refers to Table I of paper by Wing, Price and Douglass. See notes for authority for tests, etc.

Reference Number[a]	Cylinders	Average Strength, psi.	Variation, per cent		Remarks
			2 Tests	All Tests	
		DENVER RESEARCH LABORATORY			
1...	140	5900	6.0	...	Vibrated
2...	64	5800	8.1	...	Hand rodded
3...	48	4000	5.0	8.0	Boulder Dam aggregates
4...	27	3300	6.7	6.9	Boulder Dam aggregates
5...	12	4200	6.4	7.0	Parker Dam aggregates
6...	72	3300	4.8	...	Friant Dam aggregates
7...	81	4200	5.5	...	Bartlett Dam aggregates
8...	28	4300	4.8	...	Seminoe Dam aggregates
9...	231	4140	...	5.8	
Avg....			5.9	6.9	
		FIELD CONTROL TESTS			
10...	1058	5720	...	...	Grand Coulee Dam, Dec. 1935 to June 1936
11...	134	5395	...	11.5	GCD, September 1937
12...	170	5372	2.9[b]	7.2	GCD, July 1937
13-29...	3000	5500	...	...	GCD, 17 other months July 1936 to Dec. 1937
30...	4600	4150	...	12.5	Dam 1, 1938-1940
31...	133	4300	...	12.7	Dam 4, 1937-1939
32...	503	3645	...	13.9	Dam 4, 1937-1941
33...	4000	3160	...	18.2	Dam 2, 1940-1942
34...	192	2700	...	17.5	Dam 3, 1940-1941
35...	255	2560	...	19.4	Dam 3, 1940-1941
36...	39	4200	...	8.3	Medium size dam
37...	13	4170	...	8.7	Concrete lining
38...	21	4340	...	12.6	Small structures
39...	46	3740	3.6[b]	10.9	Dam B, 1939, mixed 1½ min.
40...	46	3925	2.5[b]	9.1	Dam B, 1939, mixed 2½ min.
41...	18	....	...	9.6[c]	Dam A, dry mix, 1 min.
42...	18	....	...	3.1[c]	Dam A, dry mix, 3 min.

[a] 1, 2 = "Hoover Dam Concrete Research...," by R. F. Blanks, U.S.B.R. Technical Memorandum 296, June 1, 1932.
3 = U.S.B.R. Tech. Memo. 371, 1932.
4 = U.S.B.R. "Concrete Manual," 1942. Tests made 1932.
5 = U.S.B.R. Tech. Memo. 509, 1935.
6 = U.S.B.R. Report on laboratory investigations of Friant Dam Aggregates, 1936.
7 = U.S.B.R. Tech. Memo. 557, 1936.
8 = U.S.B.R. Tech. Memo. 576, 1936.
9 = Authors' Closure to discussion of paper by Wing and Ruettgers, *Proceedings*, Am. Soc. Testing Mats., Vol. 43, p. 978 (1943).
10 = "Special Cements for Mass Concrete," by J. L. Savage, 1936, p. 182.
11 = "Mixer Efficiency or Mortar-Mix Tests," by O. G. Patch, Journal of American Concrete Institute, January 1939.
12 = Discussion by Mr. Patch, Jl. ACI, June 1939. See complete schedule of these tests, *Proceedings*, Am. Soc. Testing Mats., Vol. 43, p. 954 (1943).
13-29 = Test results have not been published. In considering each month as a separate test series of about 180 cylinders, the writer followed the precedent set by U.S.B.R. writers.
30-35 = Authors' Closure to discussion of paper by Wing and Ruettgers, *Proceedings*, Am. Soc. Testing Mats., Vol. 43, p. 978 (1943).
36-38 = U.S.B.R. "Concrete Manual," 1942, p. 195.
39-40 = Authors' Closure to discussions of paper by Wing, Jones and Kennedy, *Proceedings*, Am. Soc. Testing Mats., Vol. 43, p. 1048 (1943).
41-42 = Same as 39-40, p. 1039.

[b] It is shown in the text that these low coefficients accompanied excessive "twinning" of strengths in the cylinder tests.

[c] The coefficients given are for variations in water-cement ratio in 4-yd. batch determined from 18 samples. The variations in strength would be about double those shown. Note that this was for the "dry mix."

none of which appears in Table I of the paper. These 42 omitted series comprise twice the number of tests that were recorded in Table I of the paper. Only two of these series, on which we have definite information, gave "within-batch" coefficients as low as the average 3.39 per cent of Table I. The average within-batch coefficient in the 8 research laboratory series that were omitted was 5.9 per cent. As *variance* this is $(5.9/3.39)^2 = 3$ times the average of 3.39 per cent given in the paper.

(*b*) The writer's discussion of Wing and Ruettgers' paper (1943 A.S.T.M. *Proceedings*, p. 953) commented on the peculiar partiality of U.S.B.R. writers for the tests at Grand Coulee Dam, July 1937, and showed that the absurdly low "within-batch" variation (2.9 per cent) resulted from "twinning" of cylinder strengths.

In the tests at Grand Coulee we can trace 11 different steps in the various "selections" by U.S.B.R. writers. Concreting began in December 1935. In his original paper Mr. Patch used 134 cylinder strengths for September 1937. *Step 1.* These tests were made after the adoption of a new method of sampling, concerning which there has been considerable mystery. *Step 2.* September is likely to have the smallest weather variation. *Step 3.* The tests represented the twentieth month of continuous experience of the crews on this job, and (*Step 4*) it was the last month on this contract in which weather conditions were conducive to uniform strengths. *Step 5.* It appears that Mr. Patch omitted about 40 cylinders made in September. *Step 6.* When the writer commented on the 70 per cent spread, Mr. Patch dropped these tests, but gave strengths of 170 cylinders of July 1937 with 50 per cent spread. *Step 7.* It appears that his tabulation omitted 16 cylinders. *Step 8.* Wing and Ruettgers, wishing to illustrate typical concrete variation in their paper last year, selected the same series of tests out of hundreds of monthly series at their command, but (*Step 9*) out of 85 batches reported by Patch, they used 34, omitting the highest strengths and reported a spread of 39 per cent. *Step 10.* The writer's comments on this method of handling these tests were ignored by Messrs. Wing and Ruettgers. *Step 11.* Grand Coulee Dam tests for July or September 1937 were not used in the present paper.

(*c*) Table III included five series of tests, but only series D was used in Table I, where it became series 3. This series was "selected" on four counts: (1) The authors did not find series A, B, C, or E satisfactory, but after reading the writer's discussion of Wing and Ruettgers' paper they engaged an expert operator, with an established reputation for low variations, to make series D. (2) After series D was found to show a much lower variation than the other series, it was used as the sole representative of this investigation in Table I. (3) Series D was not used "as is," but batch 14 was discarded after testing. (4) Series D showed the highest percentage of "twinning" that has ever come to the writer's attention.

(*d*) Series 13 and 29 were made by this expert operator. To call his work "representative" misrepresents the fact as stated in the paper. It was not even representative of this carefully controlled research laboratory investigation.

(*e*) Series 7 was used twice, giving a fictitious total.

(*f*) Actual within-batch variation of ten series of U.S.B.R. tests not used by the authors gave a *variance* for laboratory tests three times and for job tests $10\frac{1}{2}$ times that shown by the average coefficient of 3.39 per cent in the paper.

(*g*) Pertinent information concerning the tests in Table I was omitted—type of aggregates, type and size of mixers, size of batch, time of mixing, method of sampling. Such factors may have exerted a significant influence on the choice of these series.

PAPER DID NOT GIVE WITHIN-BATCH VARIATION

The term "within-batch" was used throughout the text; and tables and figures gave "within-batch coefficients of variation." The expression "companion cylinders" is frequently used with the same significance. On first reading the paper, the writer was greatly puzzled to explain how such low within-batch coefficients (average 3.39 per cent) could be obtained. Of course he recalled also his criticisms of the "absurdly low" value of 2.9 per cent shown by tests of 68 batches of concrete at Grand Coulee Dam for the month of July, 1937. Much later he discovered in an obscure place near the end of the text that the authors had reported *companion tests from a single composite sample* as a measure of within-batch variation in concrete strength:

> "Considering the first clause, the small variation of companion cylinders made from a composite sample (within-batch coefficient), as compared to the much larger variation of the strengths of successive batches (interbatch coefficient), makes the requirement for tests of three companion cylinders uneconomical and of doubtful utility."

Each of the last four editions of the U.S.B.R. "Concrete Manual" (1938, 1939, 1941, 1942) required that:

> ". . . small quantities of concrete shall be taken from several points and mixed."

The 1936 "Manual" was even more explicit as to the sample:

> "It is not a quantity of material collected at random from a larger mass, but it is a systematic collection of bits, which, when assembled will contain a correct proportion of each ingredient and be representative of the larger mass."

Of course, two cylinders from a composite sample of concrete cannot by any stretch of the imagination give within-batch variation.

The whole theory and practice of statistics in all of its phases is based on the primary axiom of *random samples.* The U.S.B.R. method of sampling concrete takes exactly the opposite stand and expressly prohibits tests on random samples, and denies the whole principle of random sampling. Concrete tests made under this method of sampling are not amenable to statistical treatment.

The paper uses "within-batch" dozens of times. In no single instance is there any hint as to the size of batch, nor is there a single instance where we can be sure that we have a measure of within-batch variation. Of the U. S. B. R. papers and reports familiar to the writer, only 10 series of tests are known to give within-batch variation. Of these three things may be said:

1. All but two gave much higher variations than the average in the paper.
2. One of the exceptions was mixed longer than usual, and both series that gave the lowest coefficients showed excessive "twinning,"
3. None of these series was used in the paper.

The missing tests are described briefly:

(*a*) Eight series of tests made by the Denver research laboratory of the U.S. B.R. are listed in the accompanying Table 2 (Nos. 1 to 8). These carefully-controlled research tests gave average within-batch coefficient of 5.9 per cent.

(*b*) In two series of tests in the authors' closure to Wing and Ruettgers' paper (1943 A.S.T.M. *Proceedings*, p. 1039) water-cement ratios were determined on 18 samples from a 4-yd. batch after mixing 1 min.; and another set after 3 min.; these gave:

Mixing time, 1 min. . . . . $v = 9.6$ per cent
Mixing time, 3 min. . . . . $v = 3.1$ per cent

This shows the importance of time of mixing. For 2 min., a usual time for this size of mixer, v would be about $5\frac{1}{2}$ per cent. Water-cement ratio appears as an exponent in the strength formula, hence the strength coefficient will be about 11 per cent.

U.S.B.R. writers frequently use *variance* (proportional to the square of the coefficient of variation) as a measure of variation. In terms of *variance*, the above tests may be rated:

8 laboratory series
$(5.9/3.39)^2 = 3$ times that in paper
2 job series
$(11.0/3.39)^2 = 10\frac{1}{2}$ times that in paper

It is probable that most of the field control tests of the paper were made on composite samples, as required by the U.S.B.R. "Manual." Table I contains an undisclosed number of U.S.B.R. tests; all of which would follow the "Manual" method of sampling that has been in effect for 8 yr. or more. Other laboratories may have been influenced by the sampling methods of the "Manual." Coefficients based on such samples are no proper measure of within-batch variation; they measure only the slight differences in *duplicate tests on concrete from which variation has already been eliminated.*

TWINNING OF STRENGTHS IN CYLINDER TESTS

The authors' attack on the writer's conclusions has two prongs:

1. Attempts to show that low within-batch coefficients, similar to that at Grand Coulee Dam in 1937, were found by "20 widely distributed" "representative research and field laboratories,"

2. Suggests that the high coefficients found in earlier tests by U.S.B.R. laboratories were due to fog-room troubles.

The writer attributed the "absurdly low" value at Grand Coulee Dam to the "twinning" of duplicate tests from a batch. By twinning was meant the securing of successive cylinder strengths that were so close together as to make it apparent that other factors than mere chance were controlling the results.

Errors of Loading Concrete Cylinders.—To form the basis of a discussion of twinning, it is necessary to examine some of the errors inherent in loading 6 by 12-in. cylinders. This study is confined largely to Table III; other data used by the authors are concealed in calculated coefficients. All tests in Table III were made of the same materials and mixes, under the same essential conditions; it was, in fact, a single investigation. The cylinders are entered in the accompanying Table 3 except for ten lower than 3810 and eight higher than 4600 psi. The table shows a distinct bunching of tests. Of the 228 tests checked, 116, or 51 per cent fall on strengths corresponding to *round* thousands of pounds on the testing machine (cross-section of 6-in. cylinder, 28.3 sq. in.); 70, or 31 per cent fell on *even* thousands on the machine; 140, or 61 per cent, were computed to fall on *even* 10 psi. unit stress.

Of course, these percentages are much too high to be normal. There are 7 intervals between even thousands on the machine, hence a normal distribution is 14 per cent. Fifteen cylinders were recorded to fail at 4240, none at 4250 psi. Departures from normal are summarized:

On Testing Machine	Normal Frequency, per cent	Found in Accompanying Table 3, per cent
Round thousands of pounds. . . .	28	51
Even thousands of pounds.	14	31
Even 10 psi.	50	61

TABLE 3.—CHECK LIST OF CYLINDER STRENGTHS IN TABLE III.

Each "✓" indicates one cylinder of the strength shown in Column 1. Series given in the order in which they were made.

Strength, psi.	Series A 1941	Series B 1941	Series C 1941	Series E 1942	Series D 1944	Total	Load on Machine, lb.
Lower	✓	✓✓✓✓		✓✓	✓✓✓	10	
3810				✓		1	
3820		✓		✓✓✓		4	108 000
3830						0	
3840		✓✓		✓		3	
3850				✓		1	109 000
3860		✓✓✓				3	
3870				✓✓		2	
3880						0	
3890	✓✓	✓		✓✓✓		6	110 000
3900			✓			1	
3910		✓		✓		2	
3920				✓✓✓		3	111 000
3930	✓	✓✓✓				4	
3940		✓		✓✓✓		4	
3950						0	
3960	✓✓	✓		✓✓✓		6	112 000
3970			✓			1	
3980	✓✓	✓✓✓✓		✓✓		8	
3990				✓✓✓✓		4	113 000
4000	✓		✓✓			3	
4010						0	
4020			✓			1	
4030		✓		✓[a]		2	114 000
4040			✓		✓	2	
4050	✓		✓	✓✓✓		5	
4060				✓✓		2	
4070			✓		✓	2	115 000
4080			✓			1	
4090		✓✓✓	✓			4	
4100	✓✓	✓✓[a]	✓✓✓	✓	✓	9	116 000
4110			✓			1	
4120	✓	✓✓	✓			4	
4130				✓✓	✓	3	117 000
4140	✓✓✓				✓✓	5	
4150				✓		1	
4160			✓✓		✓	3	
4170	✓✓✓	✓	✓✓✓	✓✓✓		10	118 000[b]
4180			✓✓✓		✓	4	
4190			✓	✓✓	✓✓	5	
4200			✓[a]	✓		2	
4210	✓	✓	✓✓✓			5	119 000
4220			✓✓✓	✓✓	✓✓	7	
4230	✓	✓				2	
4240	✓✓	✓✓✓✓✓	✓✓✓✓	✓	✓✓✓	15	120 000
4250						0	
4260	✓✓✓✓		✓	✓✓	✓✓✓	10	
4270					✓	1	
4280	✓[a]	✓	✓		✓✓✓[a]	6	121 000
4290				✓		1	
4300	✓		✓		✓✓✓	5	
4310			✓✓	✓		3	122 000
4320	✓✓		✓			3	
4330						0	
4340			✓		✓✓✓✓✓✓✓	8	
4350	✓	✓			✓	3	123 000
4360			✓			1	
4370		✓				1	
4380			✓		✓	2	124 000
4390	✓		✓			2	
4400			✓			1	
4410			✓		✓	2	
4420	✓✓					2	125 000
4430			✓			1	
4440					✓	1	
4450					✓	1	126 000
4460		✓	✓			2	
4470						0	
4480					✓	1	
4490	✓	✓✓				3	127 000
4500						0	
4510	✓✓✓	✓				4	
4520				✓		1	
4530		✓✓				2	128 000
4540						0	
4550						0	
4560	✓				✓✓✓✓	5	129 000
4570						0	
4580		✓			✓	2	
4590						0	
4600	✓				✓✓	3	130 000
Higher	✓✓✓✓✓✓✓	✓				8	
Total	48	48	48	54	48	246	

[a] Average of series.

[b] Average of all series.

The computer exhibited a notable partiality for strengths ending in 40 psi.; there were 38 tests ending in 40 psi.; this is 17 per cent. Only 11 tests were recorded at loads ending in 50 psi.; or 5 per cent. Normal for both, 10 per cent.

TABLE 4.—"TWINNING" OF TESTS IN SERIES A, B, C, E, D.

Data from Table III of paper by Wing, Price and Douglass.
Series given in order of making.
Three differences are given (psi.):
a, between cylinders 1 and 2 in a batch,
b, between cylinders 2 and 3 in a batch,
c, between cyl. 3 of a batch and cyl. 1 of next batch.
The first value under series identification in the column headings is the year made; the second value is average 28-day strength.

Batch	Series A 1941 4280 psi.			Series B 1941 4100 psi.			Series C 1941 4200 psi.			Series E 1942 4030 psi.			Series D 1944 4280 psi.		
	a	*b*	*c*	*a*	*b*	*c*	*a*	*b*	*c*	*a*	*b*	*c*	*a*	*b*	*c*
No. 1	60	20	180	50	350	20	160	200	80	160	80	140	30	30	150
No. 2	320	250	430	70	110	230	110	120	260	30	0	280	60	30	190
No. 3	360	90	550	10	70	170	240	40	210	230	170	420	0	20	120
No. 4	20	0	160	70	120	0	420	60	80	370	140	190	20	0	210
No. 5	120	90	30	20	120	690	60	240	40	80	210	160	10	70	110
No. 6	120	20	40	290	260	530	180	100	340	70	70	190	40	0	60
No. 7	40	40	670	140	280	30	360	120	200	120	210	40	10	10	20
No. 8	230	230	570	30	110	260	160	180	260	180	120	130	0	0	60
No. 9	160	90	340	120	190	300	110	200	230	40	70	90	40	0	0
No. 10	280	280	120	390	400	310	80	140	70	0	200	460	40	100	170
No. 11	70	380	110	70	60	300	100	170	220	320	20	190	150	40	220
No. 12	280	100	270	240	310	410	70	70	10	40	160	280	80	40	310
No. 13	140	120	390	120	240	70	70	240	30	90	30	50	90	40	380
No. 14	180	40	160	40	0	210	240	20	200	250	210	170	40	20	780
No. 15	160	70	340	40	30	120	220	170	90	170	210	400	40	0	40
No. 16	130	150	...	260	110	...	210	80	...	250	0	40	0	20	...
No. 17	...	...	...	...	...	...	...	...	...	140	30	40	...	...	...
No. 18	...	...	...	...	...	...	...	...	...	160	60	...	...	...	...
Avg.	148	123	291	123	173	243	174	134	155	150	111	192	41	26	188
*v**	3.1	2.5	6.0	2.7	3.7	5.2	3.7	2.8	3.3	3.3	2.4	4.7	0.85	0.54	3.9
*e**	1	5	2	5	2	3	0	2	3	4	5	3	12	14	3
*f**	6	31	13	31	13	20	0	13	20	22	28	18	75	88	20

* *v* = Coefficients of variation (within-batch and inter-batch) computed from average differences as in paper.
e = Number of differences of 40 psi., or less, in a column.
f = Same as *e*, as a percentage—a measure of "twinning."

If Table 3 is turned 90 deg. to the left, the check lists become frequency-distribution diagrams and show the bunching of tests.

What we have said shows errors inherent in loading these cylinders, over and above variations due to characteristics of materials, proportioning, mixing, molding, curing, capping. We see three tendencies: (1) to "reach" for total loads in *even* thousands, (2) to record loads in *round* thousands, (3) to compute strengths to *even* 10 psi.

An error of 2000 lb. in reading and computing the load makes a difference of 71 psi. in the cylinder strength. In view of what has been said, it is seen that each cylinder strength is subject to an error of about ± 33 psi., due solely to loading operations. Therefore, in order to indicate real differences in the *quality of concrete* changes in strength must be over 33 psi. The next value that would be recorded is 40 psi. A difference of 40 psi. or less in successive cylinders is immediately suspect, since it is not likely due to chance. This creates much skepticism concerning "within-batch standard deviations" of 32, 45, 53 psi. in Table I, and in the small (and zero) coefficients given by Table III.

Another valid argument for using 40 psi. as a criterion, is that it represents a strength difference of less than 1 per cent. It is well recognized that refinements below 1 per cent are seldom realized in any single phase of concrete work. Differences below 1 per cent are in general out-of-bounds. Securing a "precision index" below 1 per cent as the combined effect of 25 variables that enter into the making and testing of concrete approaches the miraculous.

We shall now present evidences of twinning of tests in the paper, with some references to other U.S.B.R. tests that were omitted.

Within-Batch Twinning Below 40 psi.—In the accompanying Table 4 are given three differences for tests in Table III:

(*a*) Between cylinders 1 and 2 in a batch

(*b*) between cylinders 2 and 3 in a batch

(*c*) between cylinder three in a batch and cylinder 1 in next batch

The average differences were used also to compute coefficients of variation by the method described in the paper. At the bottom of the table is given the number of differences of 40 psi. or less, also the same expressed as a percentage of the number of tests. The sum of the within-batch differences (*a* plus *b*) in each series is shown below in the third column, and as a percentage in the fourth column:

Series	Date	Differences of 40 psi. or Less		Coefficient of Variation, v, per cent	
		Number	Per Cent	Within-Batch	All-Tests
C	1941	2	6	3.1	3.1
A	1941	6	19	3.1	6.3
B	1941	7	22	3.1	6.4
E	1942	9	25	2.9	4.4
D	1944	26	81	0.74	3.1
Partly corrected for twinning				3.7	6.5

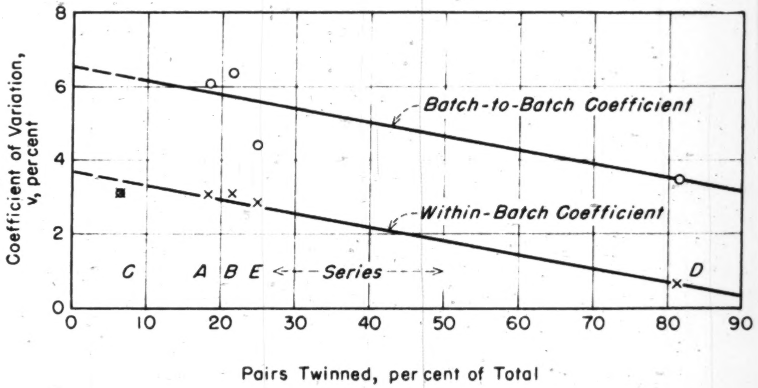


FIG. 1.—Coefficient of Variation of Concrete Corrected for Twinning of Tests.
Data from Table 4, based on Table III of paper by Wing, Price, and Douglass.

All series show "twinning" of successive tests; it was 6 per cent in series C (1941, randomized in fog room) and 81 per cent in series D (1944, expert operator). Twinning showed a pronounced increase after 1941, and was reflected in the coefficients of variation. It was so pronounced in series A, B, E, and D as to throw suspicion on many of the "within-batch" coefficients in the paper. In series D a within-batch difference of zero was reported seven times, or 22 per cent of possible cases. This is incredible from the standpoint of chance, since each cylinder is subject to an error of ± 33 psi. due to loading alone. It is apparent that no credence can be placed in the coefficient 0.74 per cent of series D (series 3 in Table I of the paper).

The paper gave a formula that states a criterion of twinning of tests in a little different form:

> ". . . the average range of pairs of observations is 1.13 times the standard deviation with but one chance in 370 of getting a value of either approaching zero or as high as 3.69 times the standard deviation."

40 psi. "approaches zero" for all influences except loading. It would be unusual to find 1 difference of 40 psi., or less, in an entire investigation of 246 cylinders, but instead we have 50 cases. On the other hand we find *no instance* of *a* or *b* differences as high as 3.69 times the standard deviation. This is conclusive proof that low deviations were not by chance.

If any one objects to 40 psi. as a criterion of twinning, it may be pointed out that if 30 psi., or 20 psi. had been used, the conclusions would have been exactly the same.

Corrections for Twinning.—In the accompanying Fig. 1 the percentage of twinning is plotted against the coefficient of variation in the paper. The points for within-batch and batch-to-batch coefficients can be represented by parallel straight lines. In drawing the upper curve no weight was given to series C, since it showed an unusual property in that the within-batch and all-tests coefficients were the same (3.1 per cent). We note here two peculiarities: (*a*) In series C, randomizing three or four times in fog room did not reduce within-batch coefficient, but reduced inter-batch variation to zero. (*b*) In series D the influence of the expert operator extended only to the within-batch coefficient which was reduced almost to zero. This eliminates the last claim of the operator who made series D to be an expert. We show below that the authors were in error in computing a zero inter-batch coefficient for series C.

The accompanying Fig. 1 shows the unmistakable dependence of the coefficients on twinning of tests in these five series. The zero ordinate represents cylinders tested under identical conditions but with no within-batch twinning indicated by differences of 40 psi. or less. Each 25 per cent of twinning lowered the coefficients about 1 per cent, that is from, say, 6 per cent to 5 per cent. The coefficients for series D (series 3 in Table I) as given in the paper, and after correcting for within-batch twinning are.

	Coefficient of Variation, *v*, per cent	
	Within-Batch	Batch-to-Batch
In paper	0.74	3.31[a]
Corrected	3.7	6.5
Correction	3.6	5.6

[a] Elsewhere in paper this is 3.5 per cent.

Subtractions are geometric; for example, $(6.5^2 - 3.31^2)^{\frac{1}{2}} = 5.6$ per cent.

It was stated in the preceding section: "both series that gave the lowest coefficients showed excessive twinning." This referred to series 39 and 40 of Table 2, tests by the U.S.B.R. on Dam B, 1939. Using 40 psi., or less, as a criterion, these series gave:

Series Number (Table 2)	Within Batch, per cent	
	Twinning	Coefficient
39 Dam B, mixed 1½ min.	22	3.6
4 Dam B, mixed 2½ min.	44	2.5
12 Grand Coulee Dam	18	2.9
Avg.	28	3.0

For comparison figures for Grand Coulee tests, July 1937, are given. It should be noted that all the above tests are entirely independent of those in Table III on which Fig. 1 was based, and were made 2 to 4 yr. earlier, yet they agree almost exactly with the indications of Fig. 1, which for 28 per cent twinning gives a within-batch coefficient of 2.7 per cent as compared with 3.0 per cent, the average of the three series above. Twinning is probably the underlying cause of many low coefficients.

Progressive Twinning.—Heretofore *a* and *b* differences in Table 4 were considered together. Here they are considered separately:

Series	Within-Batch Coefficient, per cent		
	a Differences	*b* Differences	Ratio *a/b*
A	3.1	2.5	1.24
B	2.7	3.7	.73
C	3.7	2.8	1.32
E	3.3	2.4	1.38
D	0.85	0.54	1.57
Avg., Series A, C, E, D			1.38

Series B showed insignificant twinning and is omitted from average. In the other series the second pair of cylinders showed twinning of 24 to 57 per cent more than the first pair; average 38 per cent more. Each of series C, E, and D, showed a growth in this respect over the preceding.

The same tendency was shown above in series 39 and 40, Table 2. Here the authors were endeavoring to show the merits of mixing 2½ as compared with 1½ min. The coefficient was reduced from 3.6 to 2.5 per cent, but this accompanied increased twinning from 22 to 44 per cent.

Within-Batch Twinning Above 40 psi.—40 psi. was used as a criterion of twinning, and corrections for this type were given. It cannot be assumed that this corrects for all types of twinning. The frequent recurrence of certain large *a* and *b* differences indicates that there was twinning above 40 psi. It is impossible to determine the exact amount of twinning above 40 psi., or to make a separate correction for it.

Inter-Batch Twinning is indicated to some extent in Table 4. Using the *c* differences of 40 psi. or less as the criterion:

Series	Twinning, per cent
A	13
B	20
C	20
E	18
D	20
Avg.	18

If this twinning has the same effect as the within-batch type, the all-tests coefficients in the accompanying Table 6 should be increased by about 1 per cent.

Inter-Series Twinning. The following figures indicate the tendency to carry twinning from series to series:

Series A, B, C, 1941–2, grand average	4190 psi.
Series D, 1944, first cylinder	4190 psi.
avg. batch 1	4200 psi.
avg. batch 1, 2, 3, 4	4190 psi.

Series E was not included in this comparison since it was cured in a special manner in securing information in the fog-room survey. In series D "the technique of testing was improved" along lines that were not emphasized in the paper.

Ceiling on Cylinder Strengths.—Table 3 indicates still another strange tendency that was particularly notable in series D. The tester apparently attempted to maintain a ceiling at 4340 psi. In the first 33 tests this ceiling was broken through only twice; meantime 4340 psi. (or 4350) had been recorded 8 times, or 24 per cent of all tests. Some of these tests should have been distributed at higher strengths up to 4540 psi. This would, of course, increase all coefficients of variation in this series.

Other Corrections.—It would be interesting to determine when and where twinning first entered into U.S.B.R. concrete tests, but this would lead us too far afield. It was noted in the tests at Grand Coulee Dam, July 1937, where 18 per cent twinning was found. The Denver research laboratory showed decided twinning in series B, 1941, and up to 88 per cent in series D, 1944. During 1932–1936, the Denver tests were comparatively free from twinning.

It was seen above that, when corrected for twinning below 40 psi., the tests in the five series in Table III gave an average within-batch coefficient of 3.7 per cent. This is subject to further corrections for other twinning and for the effects of composite samples. Older U.S. B.R. tests (1932–1936) gave a within-batch coefficient of 5.9 per cent and all-tests variation of 6.9 per cent. Approximate corrections for other types of twinning, plus the effect of composite samples can then be made:

Tests	Coefficient of Variation, v, per cent	
	Within-Batch	All-Tests
U.S.B.R. tests, 8 series, 1932–1936	5.9	6.9
Table III, corrected for twinning below 40 psi., as in Fig. 1	3.7	6.5
Correction	4.6	2.3

In making all-tests corrections, no attempt was made to take account of small differences in the number of tests involved.

Here again the correction to the within-batch coefficient is higher than the average, 3.39 per cent, reported in the paper. These corrections are based on the assumption that the older U.S.B.R. tests gave substantially the correct variations.

Summary on Twinning.—This study may be summarized:

1. Later tests for which we now have detailed data, exhibit the same type of twinning that was noted by the writer last year in the tests made by the U.S. B.R. at Grand Coulee Dam, July 1937. In all series for which we have data, within-batch coefficients of less than $4\frac{1}{2}$ per cent are shown to be accompanied by excessive twinning of strengths.
2. Except for series C, tests in Table III showed twinning to increase progressively from about 20 per cent in 1941 to 88 per cent in 1944.
3. All essential differences between the five series in Table III can be attributed to twinning of tests.
4. The correction to within-batch coefficient due to twinning for series D (expert operator, in a carefully-controlled research laboratory) was larger than the average coefficient reported in the paper for "20 widely distributed" "representative research and field laboratories."
5. The within-batch coefficient of series D, after partly correcting for twinning, was 3.7 per cent. As *variance* this is $(3.7/0.74)^2 = 25$ times that reported by the authors.
6. The "remarkable precision" in series D was due to twinning of tests, rather than to "improved technique" and "attention to detail" by an expert operator, as stated in the paper.
7. Twinning of strengths in the only investigation for which test data were given makes it necessary to discount all coefficients, and makes it probable that all conclusions stated in the paper are unwarranted and misleading.

When 8 U.S.B.R. laboratory series 1932–1936 show an average within-batch coefficient of variation of 5.9 per cent, and carefully-controlled laboratory tests, made 8 yr. later by an expert operator, give a within-batch coefficient of 3.7 per cent, after partly correcting for twinning, it confirms the writer's conclusion of last year that 2.9 per cent for field tests at Grand Coulee Dam was "absurdly low."

In view of the importance of twinning, the authors' closure should include the percentages of twinning in each of the 30 series.

FOG-ROOM STRENGTH SURVEY

It is difficult to guess the purpose of a fog-room survey in this paper, unless it was, as surmised above, to create the impression (without saying so) that earlier U.S.B.R. laboratory tests of concrete were extremely variable on account of fog-room troubles that came to light in 1942, but now that this difficulty has been recognized and removed, tests are much more concordant. This would dispose of the 5.5 per cent coefficient of variation pointed out by the writer a year ago, make more plausible the 3.39 per cent in the paper, and partly account for the "truly remarkable precision" in series D, 1944.

TABLE 5.—FOG ROOM STRENGTH SURVEY.
Data from Table III of paper by Wing, Price and Douglass. Series C was made December 1941; Series E, January 1942

Cylinder Number	28-day Cylinder Strengths, psi.											Coefficient of Variation of Batch Averages, v, per cent
					SERIES C, RANDOMIZED THREE OR FOUR TIMES ON SHELF							
Batch	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8			Avg.	
3	4200	4050	4110	4260	4000	4120	4220	4360	....	....	4170	
2	4400	4170	4070	4320	4240	4220	4100	4180	....	....	4210	
1	4240	4280	4310	3900	4180	4040	4460	4020	....	....	4180	
Avg.	4280	4170	4160	4160	4140	4130	4260	4190	....	....	4180	1.4
Batch	No. 9	No. 10	No. 11	No. 12	No. 13	No. 14	No. 15	No. 16			Avg.	
3	4410	4240	4380	4160	4000	4190	4340	4300	....	....	4250	
2	4210	4100	4210	4090	4240	4210	4170	4220	....	....	4180	
1	4100	4180	4310	4160	4170	3970	4390	4430	....	....	4210	
Avg.	4240	4170	4300	4140	4140	4120	4300	4320	....	....	4210	2.7
					SERIES E, ARRANGED AS CURED ON FOG ROOM SHELF							
Batch	No. 8	No. 7	No. 6	No. 5	No. 4	No. 3	No. 2	No. 1			Avg.	
3	4190	4170	3890	4050	3730	3820	3940	4050	....	....	3980	
2	4310	3960	3820	3840	3870	3990	3940	4130	....	....	3980	
1	4130	4080	3890	3920	4240	4220	3910	4290	....	....	4090	
Avg.	4210	4070	3870	3940	3950	4010	3930	4190	....	....	4020	2.9
					SERIES E, CURED ELSEWHERE IN FOG ROOM							
Batch	No. 9	No. 10	No. 11	No. 12	No. 13	No. 14	No. 15	No. 16	No. 17	No. 18	Avg.	
3	4170	4060	4220	4150	3990	3980	3770	3920	3850	3990	4010	
2	4100	4260	4200	3990	3960	4190	3980	3920	3820	4050	4050	
1	4060	4260	4520	4030	3870	3940	3810	4170	3960	3890	4050	
Avg.	4110	4190	4310	4060	3940	4040	3850	4000	3880	3980	4040	3.6

Probably no two fog rooms are alike as to size, shape, insulation, equipment and operation. No claim was made that this survey has any general application.

The authors place much weight on "the amount of fog"; this topic is discussed four times. Apparently they are unfamiliar with the past researches of their Bureau. One of the first things settled was fog-room control. Let us place the exhibits in parallel columns:

Found, 1932	Remedy, 1942
". . . curing conditions are ideal with 100 per cent relative humidity without excess moisture . . ."	". . the amount of fog supplied to the sprays was cut in half. ". . . reduction of free water in the fog sprays to an amount sufficient to maintain 100 per cent relative humidity with a minimum of free-water precipitation on the cylinders . . ."

The 1932 statement is from "Hoover Dam Concrete Research . . ." by R. F. Blanks, *Tech. Memo.* 296. The more complete statement was:

> "Complete automatically controlled air conditioning systems for all rooms have now been installed, and curing conditions are ideal with 100 per cent relative humidity without excess moisture and 70 F. temperature being maintained at all times. The equipment includes refrigeration, washers, electrical heaters and compressed air atomizers all of which are automatically controlled with compressed air controllers."

The remedy of 1942 was exactly the solution of the same problem by the same Bureau which 10 yr. earlier, according to the report of Mr. Blanks, resulted in "ideal" conditions.

The "survey" of the paper was based principally on series E; it was a serious oversight that the authors failed to give more attention to series C, made a month earlier. In Table 5 (third group) the 24 cylinders of series E are arranged as they were fixed on the fog-room shelf during the entire curing period, wall at top. (Figure 4 shows "16 sets of 3"; a note following Table III states that eight sets were on the shelf.) The ten batches in series E (last group) that were cured elsewhere in the fog room are given, and all of series C, "randomized" on the shelf three or four times (statements conflict). For comparison, series C is tabulated in two parts.

Series E shows a difference between the average strengths of cylinders 1 and 2 on the shelf of 110 psi.; this forms the basis of the contours in Fig. 3; but in series C, where randomizing tended to make all rows alike, there is a difference *between two sections of the same row of 80,* and up to 70 psi. between rows.

In Fig. 4 batch 8 occupied the position of lowest strength (3900 psi.), but it had the highest strength of any batch on the shelf (4210 psi.). The authors drew strength contours between individual cylinders on the shelf. To depend on individual tests for such a conclusion is hazardous. One can just as readily draw similar contours among the randomized cylinders of series C in the accompanying Table 5, but the authors would, no doubt, object to this as an absurd procedure.

If there was any significant difference in the various locations in the fog room, it is odd that the two divisions of series E gave more nearly the same average strengths (4020 and 4040 psi.) than the two divisions of randomized series C (4180 and 4210 psi.).

One other comparison is made of tests in series E (Table 5):

Batches	Tests	Cured	All Tests, v, per cent
9, 10	6	Randomized in fog room	2.4
11, 12	6		4.7
13, 14	6		2.9
15, 16	6		5.1
17, 18	6		2.3
Avg.			3.5
1 to 8	24	Fixed on shelf	2.9

The average strength of the shelf cylinders was almost exactly the same as the randomized; the above table shows that the coefficient of variation of the shelf cylinders was *less than the average of those randomized elsewhere in the fog room.*

Every factor that was considered above shows that the shelf truly represented the other parts of the fog room, and, as the U. S. B. R. research showed in 1932, gave "ideal" curing conditions.

If the foregoing is not enough, compare the coefficients of variation of the two parts of series E (Table 5):

All tests, 24 cyl. fixed on shelf $v = 2.9$ per cent
Interbatch, avg. of 5 sets of 6 cyl. randomized elsewhere in fog room. . . . . $v = 2.8$ per cent

It was shown above that after partly correcting for twinning, series E exhibited characteristics no different from other series; on the contrary, it blended perfectly into the general investigation.

This study, with the aid of elementary statistics, failed to reveal any measurable differences in variation of the cylinders: (*a*) fixed on the shelf, (*b*) randomized on shelf, (*c*) randomized elsewhere in fog room, and shows no basis whatever for the strength contours in Fig. 4 of the paper. The tests in series C and E contradict every conclusion drawn from them by the authors.

STATISTICAL METHODS

In discussing Wing and Ruettgers' paper last year, the writer stated:

> "A proper evaluation of test errors will make it necessary to discard most of the conclusions stated by the authors.
>
> "The paper presents an erroneous picture of the cement for dam 2, due to an improper use of statistical methods."

The authors answered:

> "Mr. Abrams' criticism of the use of statistical methods in analyzing the variations in cement and concrete for dam No. 2, on the ground that the test data are not homogeneous, is entirely out of line with the authors' interpretation of the ASTM Manual, their principal guide." (1943 *Proceedings*, A.S.T.M., p. 976).

The authors' closure to the discussion of Wing, Jones, and Kennedy's paper a year ago, after cataloging half-a-dozen of the writer's most pointed criticisms, answered them all thus:

> "Statements such as the foregoing indicate the authors should not have relied so much on the reader's familiarity with the A.S.T.M. Manual for explanation of their basic concepts." (1943 *Proceedings*, A.S.T.M., p. 1041).

Instead of giving data and engineering arguments, preceding U.S.B.R. authors merely pointed to the A.S.T.M. "Manual on Presentation of Data" as their answer to many of the writer's criticisms. The present authors refer several times to the "Manual" for statistical methods. The following discussion shows how their practices compare with their authority.

Data Must Be Good.—The entire methodology of modern statistics is based on the theory that the only way to learn the properties of an unknown "universe" is by selecting samples which are subjected to appropriate measurements or tests. This makes it obvious that the validity of each subsequent step hinges on the samples taken. It serves no useful purpose to strive for great refinement in testing technique and in mathematical analysis, if the samples are faulty. All works on statistics insist on a first requirement that the *samples must be taken at random.* In contrast, the paper took the opposite position; the principal series were not random, but "selected"; the studies were carried out on samples from a new and fictitious "universe" from which the only thing then being studied (variation) had been deliberately eliminated.

Maximum Variation.—The word *variation* occurs 50 times in the paper; 49 usages are in the sense commonly accepted in statistics; the one exception is this conclusion in the synopsis:

> "It is shown that, even in such a room, curing at different locations may cause maximum strength variations of the order of 8 per cent."

But the text states with reference to the same tests in Fig. 4:

> "The contours indicate an 8.0 per cent range in strength across the room."

A.S.T.M. "Manual" defines "maximum deviation" as the maximum difference between any single value and the average of a set. Both the "Manual" and the paper use *deviation* and *variation* as synonyms. Maximum deviation (variation) is ½ the range, or more. It is not clear what the authors meant to say, but the first quoted statement differs from the second by more than 100 per cent. The discussion above throws grave doubt on all conclusions of the paper based on the "Fog Room Strength Survey."

Zero Coefficients of Variation.—The writer has for 40 yr. maintained a nodding acquaintance with statistical literature as applied to structural materials, but he does not recall an instance of zero variation, until this paper showed zero variation of three cylinders in a batch; and in the same series the authors also found:

> "... zero value of the interbatch coefficient in series C where the cylinders were randomized while curing. ..."

The zero variation in the batch was due to twinning. Table 4 shows the above quotation to be erroneous in that series C actually had inter-batch $v = 3.9$ per cent, computed by the method used in the paper.

"*Precision Index*" is used in the paper to characterize the coefficient of variation of concrete. This term does not appear in the A.S.T.M. "Manual." The values in the preceding and earlier paragraphs show that there is nothing "precise" about the coefficients calculated by the authors. The authors state that:

> "Corrections have been applied in the present paper, and, although the results should strictly be called 'estimated standard deviations,' the adjective is dropped."

But dropping the adjective did not increase the *precision* of the estimate. A *precise estimate* is a contradiction of terms. Correction factors are quite arbitrary; styles change frequently. Coefficients may vary 50 per cent, or more, depending entirely on *whose* corrections are used. Concrete-making is not a precise art; statistics is not a precise science. The estimated coefficients do not become more precise because they are expressed to three or four significant figures, as in the paper. Even if the tests were free of all peculiarities that have been pointed out, there would be no justification for calling the coefficients "precision indices."

Variation of a Single Test.—The authors computed coefficients of variation of a "test of single batch with one cylinder," as 5.0 and 6.1 per cent. If they had made the computations they would have found that the coefficient of variation of one test is always zero.

A single test has no standing in "the science of large numbers"; none of the concepts or devices of statistics apply to it. He who accepts one test as representing a universe, does so at his own peril; statistics gives him no estimate of its significance.

Rejecting Tests of Expert Operator.—The "Manual" makes no provision for rejecting tests. To reject tests because the results do not agree with the preconceived notions of the tester is to abandon all the teachings of the "Manual."

The authors tell us: "Series D was by expert operator who followed specifications rigidly," but they immediately rejected three tests in batch 14 and explain: "noted faulty while molding." The authors cannot have it both ways. Faulty specimens would be surprising for an expert operator, but no one could seriously object if this batch had been rejected and another substituted. Evidently those then in charge accepted and intended to use batch 14; else an additional batch would have been molded. Having given these cylinders their place in the series for 28 days, it was too late to reject them after they tested 500 psi. below the average. In the accompanying Table 6, batch 14 was restored to series D and gave average strength 4280 psi. and all-tests variation of 4.5 per cent.

Attention is called also to the remarkable performance of this operator who manufactured three *faulty* cylinders that agreed as shown by 3800, 3760, 3780 psi. This gives $v = 0.66$ per cent, or lower than the 15 batches that were offered as evidence of his expert work. If this operator was expert as claimed, it is odd that he is the only one whose tests were rejected.

TABLE 6.—COEFFICIENT OF VARIATION INCREASES WITH NUMBER OF CONCRETE TESTS

Data from Table III of paper by Wing, Price and Douglass.

Based on 28-day compression tests of 6 by 12-in. cylinders molded in sets of three from a batch.

Series arranged in order of making.

Coefficients of variation corrected for number of tests.

Series	First Cylinder	First 3	First 6	First 9	First 15	First 24	First 36	48 Tests
AVERAGE 28-DAY COMPRESSIVE STRENGTH, PSI.								
A	4560	4590	4440	4480	4320	4340	4350	4280
B	3610	3690	3750	3800	3870	4000	4010	4100
C	4240	4280	4220	4200	4180	4190	4190	4200
E	4290	4160	4040	4030	3940	4010	4080	4030[a]
D	4190	4200	4140	4180	4210	4240	4280	4280
Avg.	4180	4180	4120	4160	4100	4160	4180	4180
COEFFICIENT OF VARIATION, PER CENT								
A	...	0.7	4.8	4.1	6.1	6.3	5.7	6.1
B	...	3.4	4.1	3.9	4.0	6.0	5.3	6.4
C	...	2.2	2.9	2.9	3.2	3.3	3.0	3.0
E	...	1.1	3.8	4.0	5.4	4.2	4.1	4.0[a]
D	...	0.5	2.0	2.2	2.6	2.2	2.6	4.5
Avg.		1.6	3.5	3.4	4.3	4.4	4.1	4.8

[a] Based on 54 tests from first 18 batches.

The 15 per cent Rule.—The authors endorse the 15 per cent rule for rejecting tests that has been written into a number of A.S.T.M. specifications for cement and concrete, and they rejected batch 14 of series C that was about 11 per cent below the average, practices that find no sanction in the A.S.T.M. "Manual." Much of the "Manual" is built around 270 brick tests, average strength 1000, minimum 270, maximum 2010 psi. The 15 per cent rule rejects 56 low and 50 high tests, total 106, or 39 per cent of the series. But the "Manual" (with low value 27 per cent and high 201 per cent of the average) did not reject any test.

The authors cannot point to the "Manual" as authority and at the same time reject tests 11 per cent below the average and endorse the 15 per cent rule. The 15 per cent rule is a phase of "trade-association engineering" that should have no place in A.S.T.M. specifications. The authors are requested to state the number of tests in Table I that violated the 15 per cent rule and the number in each series that were rejected.

Relevant Information Missing.—The "Manual" has much to say on Relevant Information; their explicit discussion ends with:

> "Much of this information may be qualitative in character, some may even be vague, yet without it the interpretation of the data and the conclusions reached may be misleading or of little value to others."

Much relevant information was omitted from the paper:

(*a*) Type of aggregates,
(*b*) Type and size of mixers,
(*c*) Size of batch,
(*d*) Time of mixing concrete,
(*e*) Methods of obtaining samples,
(*f*) Methods of molding cylinders,
(*g*) Handling of cylinders between curing and testing,
(*h*) Type and capacity of testing machine,
(*i*) Rate of application of load.

In order to keep this discussion within bounds only sampling and time of mixing will be considered.

Sampling.—On page 2 of the writer's first discussion of Mr. Patch's paper in 1939, a question was raised as to the methods of securing samples of concrete at Grand Coulee Dam in 1937 that was never adequately answered. Nearly all later discussions by the writer in this serious brought up this question. The present paper is notable in that it contains no word on how samples were obtained. This made it possible for the authors to present such an anomoly as within-batch variations determined by tests on composite samples.

Time of Mixing Concrete is of utmost importance. It was shown above that within-batch variation fell off rapidly as time of mixing was increased from 1 to 3 min. The coefficients of variation reported in the paper may mean much or little depending on mixing time. This question is particularly pertinent from the fact that the writer's discussion of Wing, Jones, and Kennedy's paper last year questioned the authors' law of similitude for mixers of different size. It seems likely that the mixing times in the paper would support the writer's contention (1943 *Proceedings*, p. 1034):

> "My studies of the meager *data* presented by U.S.B.R. writers indicate that concrete in a 4-cu. yd. machine is as well mixed at 1 min. as that in a 2½-cu. ft. machine."

The writer agrees with the "Manual" that "the conclusions reached may be misleading," without this information, hence it is incumbent on the authors to give data on the size of mixers, size of batch, time of mixing, and method of sampling for each of the 30 series in Table I of the paper.

TESTS OF READY-MIXED CONCRETE

In recommending that only one cylinder per batch be made in inspecting ready-mixed concrete, the authors seem to have overlooked an important phase of the subject, namely, that a modern concrete testing laboratory is a land of make-believe that has little relation to the conditions under which concrete is manufactured and used. Ready-mixed concrete in 3- to 8-yd. batches is frequently extremely variable. The mixers are not built or operated in a manner that makes for uniformity; in general the wettest part of the batch comes out first.

Another important factor, probably overlooked, is the tricky provisions for sampling in the A.S.T.M. Tentative Specifications for Ready-Mixed Concrete (C 94 – 43 T).[4] The method is not part of the specifications, but it:

> ". . . shall be so modified as to permit of obtaining two samples, one at the one-quarter point and one at the three-quarter point of the batch."

The samples thus obtained must then be mixed to form a composite. This device estops the purchaser from making any tests with a view to determining the true variations in slump or strength. Nor is that all; he is specifically prohibited from taking samples near the beginning or the end of discharge, the very points where the concrete is most certain to be erratic in composition.

When a building code specifies concrete of minimum strength of 3500 psi. at 28 days, each batch and each portion of every batch must equal or exceed that extremely modest strength requirement. All variations must occur at higher strengths. Inferior concrete in a basement column cannot be averaged with a few better batches in a roof slab, although that fantastic theory has been included by the Society in the Tentative Specifications for Ready-Mixed Concrete.

Laws of chance (or of statistics) cannot be applied to structures where the lives and property of the community are at stake. Reinforced-concrete buildings, bridges, or large concrete dams cannot be erected with the expectation that:

> "If as many as 5 in 100 fall outside the same [control] limits, poor control is indicated."

In concrete construction *nearly right* is not good enough; the only permissible score is 100.00 per cent right.

---

[4] 1943 Supplement to Book of A.S.T.M. Standards, Part II, p. 105.

The practice of testing three cylinders from a batch of ready-mixed concrete should be continued. The privilege of taking samples from any part of the batch should be restored to the purchaser.

ATTEMPTS TO GERRYMANDER DISCUSSIONS

Obviously with a view to disarming critics the paper stated:

> "Discussion of variations in interbatch precision is beyond the scope of this paper."

A second such attempt is found in the footnote to Table I:

> "These coefficients computed from data but may well not be typical."

If these coefficients "may well not be typical," why are we asked to accept column 4, computed by the same men from the same data?

The writer found it practically impossible to discuss the paper and exclude all-tests variations. Apparently the authors discovered the same thing. Inter-batch and batch-to-batch variations are shown in Table I and elsewhere, and are discussed no less than a dozen times in the paper. The important conclusion in the third sentence of the synopsis hinges on inter-batch variation. Under the circumstances the authors have no license to gerrymander discussions to exclude over-all variations, especially since they found that batch-to-batch variation is the only one of importance.

NEW STRENGTH-VARIATION LAW FOR CONCRETE

The writer's discussion of Wing and Ruettgers' paper last year stated 3 principles, all of which are believed to be new:

1. "There is strong evidence that the usual correction factors for number of tests are too low when applied to cement and concrete. (1943 *Proceedings*, p. 961).

2. "Variation in concrete and cement tests increases as a logarithmic function of the number of tests . . . (p. 948).

3. "If we examine almost any series of tests in which concretes of different strengths were tested, we find that v is low for high-strength concrete and high for low-strength." (p. 957).

TABLE 7.—EFFECT OF CONCRETE STRENGTH ON COEFFICIENT OF VARIATION

Data from Table I of paper by Wing, Price and Douglass.

Series grouped in three strength ranges, using 17 series for which batch-to-batch coefficients were given.

Series	Number of Tests	28-day Strength, psi.	Coefficient of Variation, per cent		Maximum Size of Aggregate, in.
			Within-Batch	Batch-to-Batch	
STRENGTH RANGE 2510 TO 3500 PSI.					
No. 18	60	2770	4.9	14.8	1½
No. 19	90	2980	1.5	10.2	
No. 25	158	3230	4.7	20.0	
No. 29	255	2560	2.5	17.4	
No. 30	646	3020	3.1	16.6	
Avg.	242	2910	3.3	15.8	
STRENGTH RANGE 3510 TO 5000 PSI.					
No. 3	45	4320	0.7	3.3	1½
No. 6	528	3840	3.0	8.2	
No 10	96	4050	6.2	10.2	
No. 26	200	4480	3.9	11.7	
No. 27	302	3550	3.7	23.0	
No. 28	312	4640	3.1	12.3	1, 1½
Avg.	247	4160	3.4	11.5	
STRENGTH RANGE 5010 TO 7000 PSI.					
No. 16	50	6900	2.8	4.0	⅜
No. 20	106	5470	4.7	14.3	
No. 21	110	5600	4.7	7.2	
No. 22	122	6160	0.9	4.3	
No. 23	116	6170	1.9	5.4	
No. 24	152	5870	4.7	6.5	
Avg.	109	6030	3.3	7.0	

Confirming 1 and 2 a relation was found of the form:

$$v = a + b \log n \quad \ldots\ldots\ldots (1)$$

where v is coefficient of variation, n is the number of tests, a and b are constants. Sufficient data were not then available for a quantitative relation to be worked out for strength.

The present paper furnishes remarkable confirmations of all the above principles. In answer to the question: "Does variation increase with the number of tests?" the five series in Table III were studied by computing the coefficient of the first 3, first 6, first 9, first 15, first 24, first 36, and for 48 tests. Values are given in Table 6. Coefficients were computed by the square-root-mean-square method, hence final values do not always agree with those obtained by the short method of the paper. In the accompanying Fig. 2 average coefficients are plotted against number of tests. Since this was a single investigation, by using average coefficient, 4.8 per cent, for 48 tests and the coefficient of the average strengths of the series, 2.8 per cent, we compute, $(4.8^2 + 2.8^2)^{\frac{1}{2}} = 5.6$ per cent, which is another point on the curve. This point for 246 tests falls on the same straight line (curve) that had already been defined by the other tests. Curve *A*, for 4180-psi. concrete is represented by:

$$v = 2\tfrac{1}{2} + 1\tfrac{1}{4} \log n \ldots\ldots (2)$$

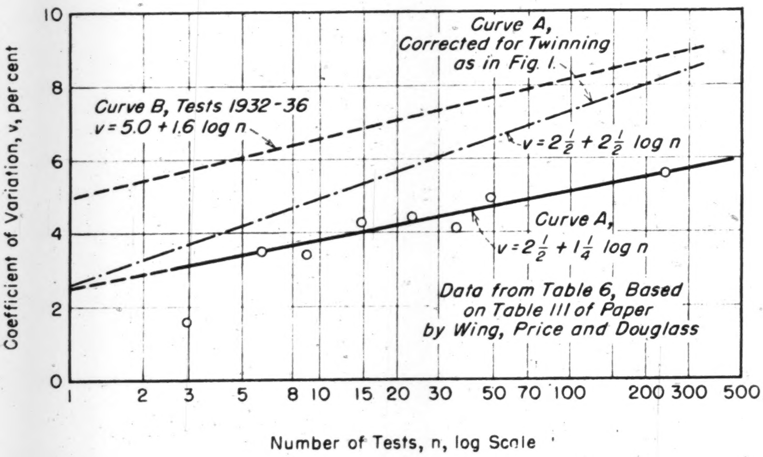


FIG. 2.—Coefficient of Variation of Concrete Increases with Number of Tests.
(Tests by U. S. Bureau of Reclamation.)

The curve obtained by the writer last year, based on six U.S.B.R. series, 3900-psi. concrete, is shown as curve *B*; its equation:

$$v = 5.0 + 1.6 \log n \ldots\ldots (3)$$

Both U.S.B.R. series show *v* to increase as a logarithmic function of the number of tests. The low position of curve *A* from the present paper is due to tests on composite samples and twinning of strengths.

Figure 2 shows also the position of curve *A* after correcting for within-batch twinning below 40 psi., $v = 2\frac{1}{2} + 2\frac{1}{2} \log n$.

Table I of paper, based on tests from "20 widely distributed" "representative research and field laboratories" gave definite information on items 2 and 3 above. In the accompanying Table 7 tests from Table I of the paper are grouped in strength ranges: 2510 to 3500, 3510 to 5000, 5010 to 7000 psi., using 17 series for which batch-to-batch coefficients were given. These ranges were not arbitrarily chosen. Each has a spread of about 40 per cent from the minimum value and contains about one third of the series.

The accompanying Fig. 3 shows the effects of both number of tests and strength of concrete on coefficients of variation. The point for $2\frac{1}{2}$ tests for the middle strength group is plotted from the value, 3.3 per cent, in Table I; average based generally on 2 or 3 tests. The within-batch variations in Table I did not discriminate between concretes of different strengths, hence corrections taken from Fig. 2 of the paper were applied in order to secure the other points for $2\frac{1}{2}$ tests. For example, 6030 psi. represents an increase of 45 per cent over 4160 psi. Figure 2(*a*) shows that the above average of 3.3 per cent must be increased 20 per cent, or a corrected coefficient of 4.0 per cent. Similarly, the point for 2910 psi. represents a minus correction of 25 per cent, or a corrected coefficient of 2.6 per cent. These corrections are unimportant factors in plotting Fig. 3. Their use avoids a slight inconsistency in having the upper and lower curves cross at $2\frac{1}{2}$ tests. If these corrections had not been applied, the principles deduced from the figure would have been exactly the same, and the constants *a* and *b* would have been changed by insignificant amounts.

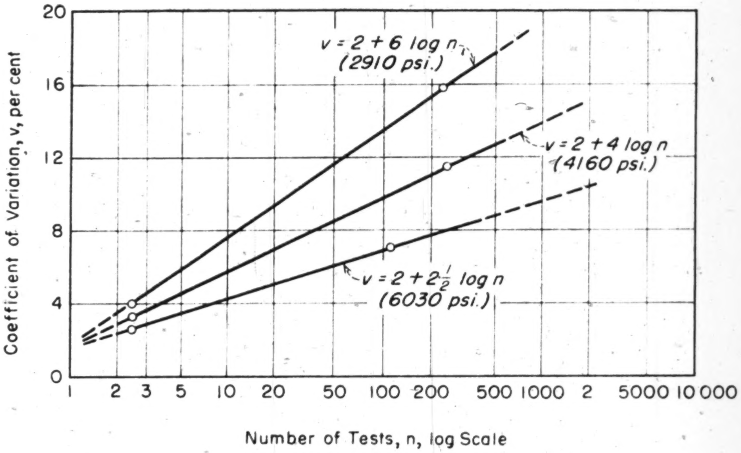


FIG. 3.—Coefficient of Variation of Concrete Increases with Number of Tests.
Data from Table 7, based on Table I of paper by Wing, Price, and Douglass.

The all-tests coefficients are the averages from the accompanying Table 7. For sake of simplicity the individual points are omitted from Fig. 3. It may be objected that two points cannot establish the position of an exponential curve. That is true in general, but it was shown above that the intermediate points defined this type of curve in the U.S.B.R. tests studied in the writer's discussion of Wing and Ruettgers' paper as did also the tests in Fig. 2 from the paper.

The curves in Fig. 3 may be represented by these expressions:

Strength, psi.	Expression for *v*, per cent	Coefficient of Variation, *v*, per cent	
		10 tests	100 tests
2910	2 + 6 log n	8	14
4160	2 + 4 log n	6	10
6030	2 + 2½ log n	4½	7

The constants *a* and *b* were determined from Fig. 3; for convenience they are expressed in percentages; $a = 2$ per cent for all strengths, but b is an inverse function of strength.

Great refinement is impracticable in view of the limited data, hence values of a and b are generally given to the nearest whole number, and other constants are expressed only in round numbers that readily may be in error ± 10 per cent.

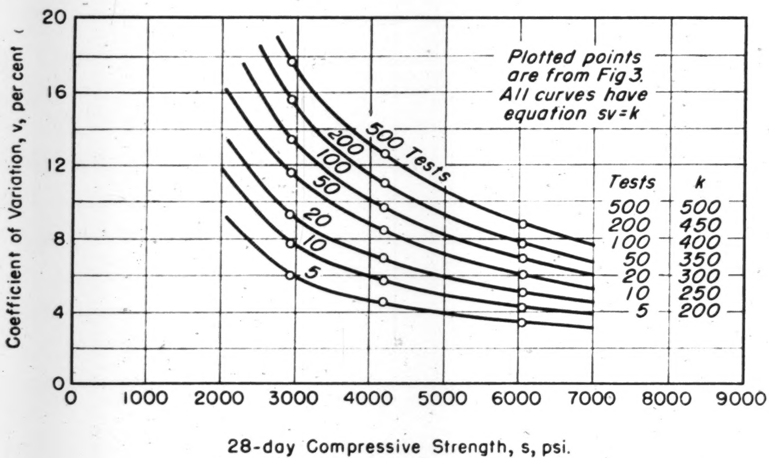


FIG. 4.—Relation Between Compressive Strength and Coefficient of Variation of Concrete.

Table 7 indicates that strength of concrete is the determining factor, rather than size of aggregate as stated in the paper.

Data in Fig. 3 are more usable if the values are set up with 28-day concrete strength as the principal argument, separate curves being drawn for certain numbers of tests, as in the accompanying Fig. 4. In drawing these curves the writer was guided by a number of considerations in addition to the three points from Fig. 3. Experience leads us to expect high coefficients for strengths below, say, 2000 psi. On the other hand, we would expect coefficients to become lower as strengths over, say, 7000 psi. are reached. Since 14,000 psi. is a ceiling beyond which strengths cannot normally go, it seems likely that the coefficients would become negligible in this region. The curves that pass through the three given points and conform to the other requirements are essentially rectangular hyperbolas, approximately asymptotic to both axes. The curves in Fig. 4 have equations similar to the well-known "gas-law"; that is:

$$sv = k \qquad \qquad (4)$$

where s is 28-day concrete strength (psi.) and k is a constant for a given number of tests.

Equations 1 and 4 represent the same data, hence:

$$k = (a + b \log n)\, s \qquad \qquad (5)$$

The value of k can be computed for a given number of tests. For 10 tests of 4160-psi. concrete, $k = (0.02 + 0.04)\ 4160 = 250$ psi. But 250 psi. holds for all strengths, so long as we have ten tests. For other numbers of tests:

Tests	k psi.
5	200
10	250
20	300
50	350
100	400
200	450
500	500

Two examples are given: (*a*) 100 tests of 3300-psi. concrete, v = 400/3300 = 12 per cent; (*b*) 10 tests of 5000-psi. concrete, v = 250/5000 = 5 per cent. These are the percentages shown by Fig. 4.

The above values of k are based on the data in Table I. In the writer's opinion all values should be much higher, especially for the smaller numbers of tests. Figure 2 shows curve A corrected for within-batch twinning of tests. The curve intersects curve B, based on older U.S.B.R. data at about 1000 tests. One might readily assume that differences between curves A and B were chargeable to twinning and to tests on composite samples.

The paper stated:

> "As a rough rule, the data show that a given percentage change in average strength produces 60 per cent of that change in the value of the within-batch coefficient but in the opposite sense. Tests on 2000-psi. concrete would, therefore, be expected to have about a 30 per cent higher coefficient than 4000-psi. concrete."

Equation 4 may be written: $v = k/s$. In other words, the coefficient varies inversely as the strength. Contrary to the authors' conclusion, the data of the paper show that v of 2000-psi. concrete is 100 per cent higher than for 4000-psi. concrete.

The new strength-variation law for concrete may be stated:

> "The coefficient of variation of concrete cylinders tested at 28 days increases as a logarithmic function of the number of tests, and for a given number of tests, varies inversely as the strength of the concrete."

In their closure last year Wing and Ruettgers presented an interesting reaction to the writer's conclusion that the coefficients of variation in cement and concrete tests increase as logarithmic functions of the number of tests. The writer's Fig. 2 (1943 *Proceedings*, p. 957) gave the basis for the above law, but the authors rejected that evidence as (1943 *Proceedings*, p. 974):

(*a*) ". . . a heterogeneous assembly of 'coefficients of variation' . . .",

(*b*) " . . . use of data of large inherent error . . ."

The *only data* used in plotting the figure were from the Wing and Ruettgers paper, then under discussion, or from other U.S.B.R. reports to which references were given. The only method of refuting the writer's conclusion that appealed to the authors was to discredit the data on which their own paper was based and similar data published by other U.S.B.R. writers.

Two groups of U.S.B.R. authors ignored suggestions made last year. This now enables the writer: (*a*) to correct some of the numerous glaring errors in the paper; (*b*) to present a new and important law of concrete technology, based on their tests.

MESSRS. S. P. WING,[5] WALTER H. PRICE,[5] AND CLEMEUNT T. DOUGLASS[5] (*authors' closure, by letter*).—The authors' paper had only two purposes: first, to make a representative survey of laboratories to determine the reproducibility of results of strength tests of companion cylinders compositely fabricated from a single sample or from a small, well-mixed laboratory batch, and tested under conditions most favorable to uniformity; the index of variability used was the coefficient of variation and was referred to as the "within-batch" coefficient; second, to show how the variability index could be practically applied to the bettering of specifications and to the analysis of research.

Mr. Abrams questions the suitability of data supplied to the survey by one of the 13 contributors. In his opionion the data from this source required corrections and were not representative. Considering that the survey covered 6000 tests, all the material from the source in question could have been omitted without materially changing the paper's conclusions. Moreover other data which have since been reviewed, including some from Mr. Abrams' own work, seem to confirm the general applicability of the authors' conclusions.

---

[5] Engineers, U. S. Bureau of Reclamation, Denver, Colo.

Mr. Abrams deals at some length with expected variation between cylinders which have been molded from different samples taken from different locations in a large mixer drum. The authors' survey only applied to *composite companion* cylinders. Had the authors defined the variation they were discussing as the "within-sample" coefficient rather than "within-batch" coefficient, perhaps confusion to those unfamiliar with the term "companion" would have been avoided. Its only relation to the variation of cylinders molded from different samples from the same batch is that of being the limit which their variation approaches as mixing becomes complete.

Mr. Abrams points out that one among the many factors which cause variations in recorded strength of cylinders intended to be of the same strength is the inability of the test engineer to read the test dial closer than a certain minimum. Cylinders recorded to be of the same strength he calls "twinned" cylinders. He believes "within-batch" coefficients computed from average ranges based on data containing "twinned" values to be much too low and applies a maximum correction of 500 per cent.

About 60 per cent of his discussion was devoted to twinning, the development of a statistical *law* to apply only to concrete, to the rejection of observations, and to other statistical matters. Though all of his treatment of these subjects is contrary to the authors' understanding of statistical procedures and the authors are extremely dubious as to the conclusions, an adequate discussion is beyond the scope of a closure. A few published references bearing on the points raised are given in the footnote.[6] In any case, the authors feel that even should a more rigid statistical treatment of their data reveal deficiencies in their analysis, necessitating small changes in the coefficients, their conclusion that attention paid to batch-to-batch variation is more likely to produce productive results than additional study or tests devoted to within-batch control is not likely to be altered.

The statistical analysis of strength variations of cylinders cured in a fog room was presented solely as an example of the method by which the "within-batch" coefficient could be put to practical use. The acceptance by readers of the conclusions drawn, conclusions questioned by Mr. Abrams, is not necessary. Provided the authors made the application of the statistical method clear, the example has served its purpose.

After all statistical methods are never absolute. They only provide, from information extracted from the data, numerical odds that "chance" may have produced the observed distribution of data values. In the fog room test series, the odds against chance being the sole factor responsible for the increase in strength indicated along the curing shelf are high but if Mr. Abrams chooses to take the short end of a bet and criticize the authors' conclusions on the basis that "chance" was the only factor present, no useful answer can be made until future tests lengthen or shorten the odds for the "inference" indicated.

In conclusion the authors wish to

---

[6] Rejection of observations; Paul R. Rider, "Criteria for Rejection of Observations," Washington University Studies, *Science and Technology No. 8*, 1933.

Distribution of ranges and effect of grouping; W. A. Shewhart, "Economic Control of Quality of Manufactured Product," D. Van Nostrand Co., Inc., New York, N. Y., 1931.

Sheppard's correction; Peters and Voorhis, "Statistical Procedures and Their Mathematical Bases," McGraw-Hill Publishing Co., New York, N. Y., 1940.

present a brief analysis of some excellent data published by Mr. Abrams 28 yr. ago,[7] directly bearing on several points which he raised.

Single cylinders were formed from 144 batches of concrete which were mixed over a 6-day period. Each day three mixes were used, 1:9, 1:5, and 1:3. The test conditions were kept essentially uniform.

The test results can be arranged into 18 sets of 8 cylinders each, the characteristic of each set being that the cylinders came from different batches, of the same mix, from batches made on the same day. The coefficient of variation from such a set, the "within-day" coefficient, measures the ability of an operator to reproduce cylinders of the same strength from different batches mixed the same day.

Likewise, by combining the test results differently, 24 sets of 6 cylinders each may be obtained in which case each set contains only cylinders of the same mix but coming from batches mixed on different days. Variation within these sets may be called "within-week" variation, the cylinders being made on different days of the same week.

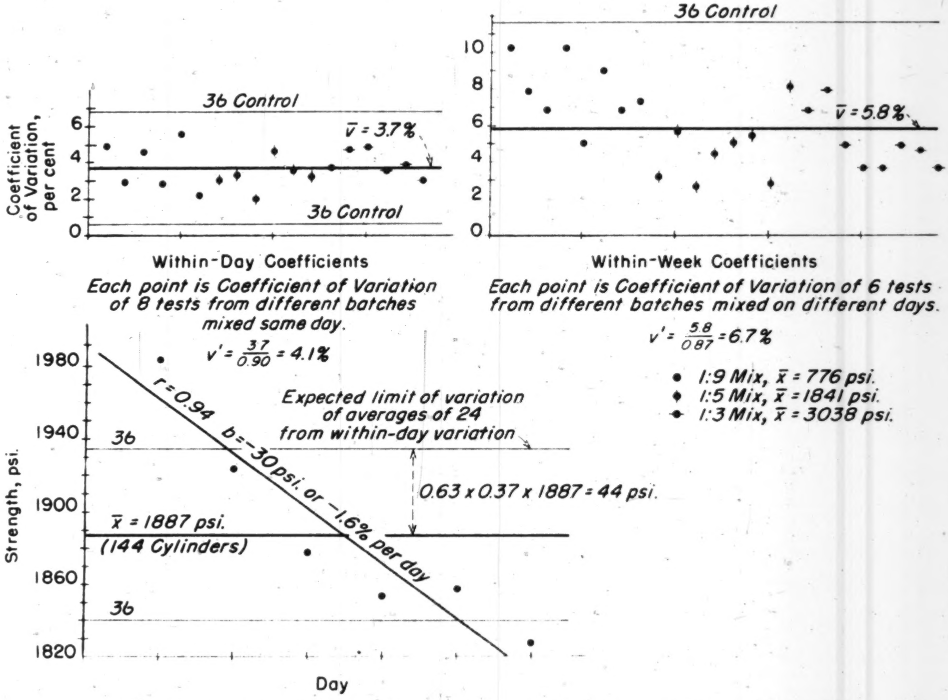


FIG. 5.—Comparison of Within-Day and Day-to-Day Strength Control from 144, 6 by 12-in. Cylinders.

Data from Table IV, D. A. Abrams, "Effect of Rate of Application of Load on the Compressive Strength of Concrete," *Proceedings*, Am. Soc. Testing Mats., Vol. XVII, Part II, p. 373 (1917).

These two kinds of coefficients are plotted in the form of control charts at the top of the accompanying Fig. 5. In the "within-day" chart, the first six plotted points are from tests on the 1:9 mix ($\bar{X}$ = 776 psi.), the second six from the 1:5 mix ($\bar{X}$ = 1841 psi.), and the third six from the 1:3 mix ($\bar{X}$ = 3038 psi.). The same arrangements are used for the "within-week" chart, but with eight points for each mix. The average strength of all tests was 1900 psi.

---

[7] D. A. Abrams, "Effect of Rate of Application of Load on the Compressive Strength of Concrete, Table IV, *Proceedings*, Am. Soc. Testing Mats., Vol. XVII, Part II, p. 373 (1917).

The greater average coefficient of variation of cylinders from batches made on different days, 5.8 per cent, as compared to cylinders from batches made the same day, 3.7 per cent, clearly indicates some factor not controlled by the experimenter introduced a day-to-day variation which was not present for tests of batches made on the same day. This factor was not random, but was persistent, as is shown by the day-to-day plot of average daily strength shown at the bottom of Fig. 5. Statistically the decrease in strength indicated, 1.6 per cent per day, is highly significant.

Whether this strength decrease might have been caused by the location of the cylinders during curing(sand-cured) or whether it might be connected with temperature control or other factors the authors are not in a position to say. Its interest to this paper is that by aid of the "within-day" coefficient, this test series, like that of the authors' fog room series, is shown to lack statistical control. A range between Monday's and Saturday's strength of 8 per cent is indicated.

This 1917 test series, both in its original analysis and in the results, contradicts at almost every point Mr. Abrams' present discussion. His own analysis of variation was made without correcting for the 30 per cent "twinning" present in the data, and results were given in terms of "estimated" coefficients of variation (labelled per cent mean error), two procedures which he now condemns. While Mr. Abrams' "estimated" coefficients were obtained by dividing the "sum of squares of deviations" by one less than the number of tests, rather than by using a table as in the control chart method, his results, 3.9 and 6.4 per cent for the "within-day" and "within-week" coefficients, are only 5 per cent different from the 4.1 and 6.7 per cent results shown by the control chart method. This is not a 50 per cent variation in "estimated" coefficients dependent on method used, as he suggests.

Mr. Abrams' logarithm "strength variation" law is not verified by this test series. The actual within-day coefficient of variation for sets of *six* is 5.8 per cent; but for the within-day sets of *eight* the result is 3.7 per cent. Instead of the coefficients increasing in value with increased number of observations per set as his law demands, they decrease.

The magnitude of the estimated "within-day" coefficient, 4.1 per cent, is particularly interesting. That 28 yr. ago Mr. Abrams was able to fabricate and test cylinders from *different* batches of 1900 psi. concrete, whose coefficient of strength variation, 4.1 per cent, is within the control limits for modern *within-batch* testing is indeed a tribute to his pioneering work in developing test techniques. In fact only two out of five of the authors' batch-to-batch test series equalled this result. Mr. Abrams believes that 4000-psi. concrete should have about one half the variation of 2000 psi. concrete, an effect of strength levels the author's tests do not indicate. But accepting his estimate for the moment, on this basis had he used 4000- instead of 2000-psi. concrete in his 1917 test series, on his own estimate his 1917 "within day" coefficient would have been reduced to 2 per cent. While only five of the authors' within-batch series shown on Fig. 1 represented as good control of technique as this, it is hard to see why those who reached it should be criticized for having "super-duper" results.

The authors wish to thank Mr. Abrams for his critical reading of their paper, even if they cannot agree with his conclusions. From the tenor of Mr. Abrams' discussion of within-batch variations (pp. 854, 857, and 867) it becomes evident that the title and the wording used by the authors was amenable to misinterpretation. Unquestionably the following suggested re-wordings would have been better.

1. Change the title to read: "Precision Indices for Comparison Tests of Companion Concrete Cylinders*" and append a footnote as follows: "*Companion cylinders as used in this report means cylinders compositely molded from the same sample of concrete. Their variation is referred to as 'within-batch' variation."

2. Substitute "range" for "variations" in the last sentence of the paper's synopsis.

The authors regret their failure to have foreseen the possibility of valid confusion which has added materially to the length of Mr. Abrams' discussion and which may also have troubled other readers.

The words of appreciation of Messrs. Pratt and Leavitt commenting on the labor involved in presenting variation data are particularly welcome and leave the authors with the hope that their survey will contribute to improved arrangements of test procedures, and to a reduction in the number of tests now made on companion cylinders.

THE MEASUREMENT OF CONCRETE STRENGTH BY EMBEDDED PULL-OUT BARS

By Bailey Tremper[1]

Synopsis

The difficulties of making an accurate estimate of the strength of concrete in structures during the curing period by means of test cylinders are well known. A principal source of error is the difference in environment between the test cylinder and the actual structure. A group of Russian engineers has experimented briefly with several means of determining the strength of concrete in place. One of the most promising methods consisted in embedding the enlarged ends of iron bars a short distance from the face of the concrete while it was being placed. The force required to pull the bar out of the hardened concrete was used as a measure of strength.

This paper reports the results of a laboratory investigation in which 120 pull-out specimens and 120 cylinders were cast from 30 batches of concrete. Mixes and test ages were varied over usable ranges. Both uncrushed and crushed gravels were used as coarse aggregate. The coefficient of variation of pull-out tests was only slightly greater than that of compressive strength tests. A high degree of correlation exists between the two tests. The data indicate that a relatively simple equation can be applied to results of pull-out tests to obtain the equivalent compressive strength up to values of 3500 psi. The method does not appear to be suitable for concrete of higher strength.

It is contemplated that field tests would be made with a dynamometer or a gage-equipped hydraulic jack. The locations in the structure at which pull-out bars would be installed could be selected with a view to final appearances.

The test has the advantage of giving direct indication of the strength of the concrete in the structure. It is free from the complications which arise when an attempt is made to cure separately-cast specimens in the same manner as the concrete in the structure.

Engineers responsible for the control of concrete are perennially faced with the necessity of making decisions as to the strength of concrete in structures during its earlier stages. Questions arise as to the safety of removing falsework, unwatering foundation seals, or permitting the imposition of design loads. Such questions become particularly acute during cool weather or whenever the need to utilize the structure is urgent.

As a rule, judgment as to the strength of the concrete is based on results of test cylinders, usually 6 by 12 in. in size. Consideration of the curing conditions to which the cylinders have been subjected when compared with probable conditions within the structure frequently leads to misgivings as to the soundness of the data upon which a decision must be based. This is particularly true when the site of the work is at some distance from the testing laboratory.

---

[1] Materials Engineer, State of Washington Dept. of Highways, Olympia, Wash.

As an illustration the following hypothetical case may be considered:

A concrete viaduct is being constructed late in October. The weather is moderately warm during the day but falls to 28 to 30 F. each night. No protection other than the forms and an earth covering on the slab has been provided. It is desired to remove the falsework under the girders at the earliest safe date and it is considered that the concrete should have a minimum strength of 2500 psi. when this is done. Test cylinders are made and are left standing on the ground for 8 hr. after which earth is placed around them for protection during the night. The following morning they are placed on top of the slab and covered completely with earth. On the seventh day they are shipped by express to the laboratory which is 200 miles distant. They are not delivered until the ninth day. Two cylinders are placed in water at 70 F. in preparation for testing on the tenth day, the remainder being buried in earth outside the laboratory. Subsequent tests indicate that the cylinders have reached the desired strength of 2500 psi. at the age of 16 days. What is the strength of the concrete in the structure? Investigation shows that only from the second to seventh days were the cylinders maintained at a temperature known to be close to that of the structure. Temperatures during the period of shipment are unknown. Temperatures at the site of the laboratory are found to have averaged 10 deg. higher than at the structure.

When the tendency of job inspectors to neglect standard procedure in making test cylinders and the difficulty of compensating for uneven ends of specimens is considered, errors as great as 20 per cent are not improbable. Clearly some form of test of the concrete in the structure itself would be much more reliable.

Lord,[2] Edwards,[3] Scofield,[4] and Young[5] have commented on the disparity between the strength of test cylinders either job- or laboratory-cured and that of the actual structure. Tests of cores cut from the hardened concrete have occasionally be used, but the expense and inconvenience of this method have militated against its general adoption.

Skramtajew[6] has described methods of estimating the strength of concrete in place as studied by a group of Russian engineers. The best results were obtained by Volf's method which consists of measuring with a special dynamometer the force required to pull out a rod whose enlarged end had been cast in the concrete at the time of pouring. Volf derived a coefficient relating pull-out and compressive strengths and found a maximum divergence of 9 per cent from the average coefficient. The concretes investigated, however, were in the lower strength ranges, from approximately 200 to 1500 psi.

This paper presents results of laboratory studies of pull-out and compression tests of concrete over a range of strengths more nearly in accord with those assumed in present-day design practice.

SCOPE OF TESTS

Of a large number of variables that could well have been considered, a few that seemed most pertinent to average construction were selected for this study. It was determined to limit the type of concrete studied to that ordinarily used in reinforced structures. Only one maximum size of aggregate ($1\frac{1}{4}$-in. square opening) was included. Concrete containing larger aggregate, such as that used in pavements, was not included because the strength of such slabs is usually estimated from relatively large beams that are cured and tested at the site of the work. The disadvantages of using test cylinders are greatly reduced by such methods. All concrete was mixed to a 3 to 4-in. slump, since this consistency generally can be placed when vibrators are used. Six mixes with cement contents ranging from 4.2 to 7.6 sacks per cu. yd. and corresponding water-cement ratios of 8 to 4 gal. per sack were considered to cover an adequate range. Test ages were 4, 6, 9, and 14 days. These were selected because of their approximate equal spacing on a logarithmic scale and because of their convenience in testing. The tests were not extended to later ages because the primary purpose was to study strengths developed during early stages of hardening. The aggregate was typical of that produced from glacial deposits in the Puget Sound area of Washington. It is of excellent quality and is rounded to subrounded in shape. In one mixture, the effect of angularity of aggregate was studied by mixing equal weights of crushed gravel to each size of natural gravel. The sand in this mix contained 11 per cent of the crushed gravel screenings. Type II cement[7] was used throughout. The specimens tested were 120 pull-out specimens and an equal number of 6 by 12-in. cylinders for compression specimens. For each mix and test age, five specimens were made, each on a different day.

---

[2] Arthur R. Lord, "Notes on Concrete-Wacker Drive," *Proceedings*, Am. Concrete Inst., Vol. 23, p. 28 (1927).

[3] Harlan H. Edwards, "Progress in Determining the Relation Between Test Cylinders and Concrete in the Structure," *Proceedings*, Am. Concrete Inst., Vol. 26, p. 57 (1930); "Properties of Job-Cured Concrete at Early Ages," *Proceedings*, Am. Concrete Inst., Vol. 33, p. 41 (1937).

[4] H. H. Scofield, Discussion of "Properties of Job-Cured Concrete at Early Ages," *Proceedings*, Am. Concrete Inst., Vol. 33, p. 64 (1937).

[5] Roderick B. Young, "The Field Testing of Concrete," *Proceedings*, Am. Soc. Testing Mats., Vol. 27, Part II, p. 390 (1927).

[6] B. G. Skramtajew, "Determining Strength for Control of Concrete in Structures," *Proceedings*, Am. Concrete Inst., Vol. 34, p. 285 (1938).

TEST METHODS

Batches of concrete of about 2 cu. ft. in size were mixed in a Lancaster type SW mixer. Four compression cylinders and four pull-out specimens were made from each batch. One of each was tested at each age. Specimens were removed from molds after 24 hr. and were then stored in a fog room at 70 F. until tested.

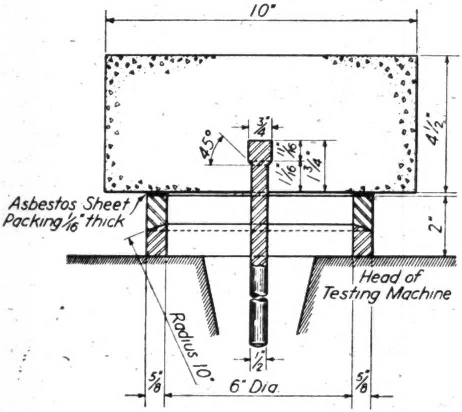


FIG. 1—Section Showing Pull-Out Specimen in Place for Strength Test.

The 6 by 12-in. cylindrical compression specimen was made and tested in accordance with A.S.T.M. Standard Method of Test for Compressive Strength of Concrete (C 39 - 42),[8] except for the method of mixing as described above. The rate of loading was 35 psi. per sec.

The pull-out specimen as cast was 10 by $4\frac{1}{2}$ in. in plan by 10 in. high. The pull-out bar was $\frac{1}{2}$-in. in diameter with an enlarged cylindrical end $\frac{3}{4}$ in. in diameter and $\frac{11}{16}$ in. in length. This shape was adopted for ease in machining. Details of its design and its position in the specimen are shown in Fig. 1. The bar passed through a hole in the center of a piece of $\frac{3}{4}$-in. plywood which constituted one face of the form. It was fixed in position by means of a set collar and a metal plate which was screwed to the form. Concrete was placed in two layers, each of which was puddled with 25 strokes of a $\frac{5}{8}$-in. bullet-nose rod.

---

[7] See A.S.T.M. Standard Specifications for Portland Cement (C 150 - 42), 1942 Book of A.S.T.M. Standards, Part II, p. 1.

[8] 1942 Book of A.S.T.M. Standards, Part II, p. 391.

TABLE I.—GRADING OF AGGREGATES.

Coarse		Fine	
Screen Size Square Openings, in.	Per cent Passing	U. S. Sieve	Per cent Passing
1¼	100	No. 3	100
1	80	No. 4	96
¾	60	No. 6	88
⅜	10	No. 8	80
¼	0	No. 16	65
		No. 30	45
		No. 50	11
		No. 100	1

TABLE II.—PROPORTIONS OF CONCRETE MIXES.

Mix	Cement, sacks per cu. yd.	Proportions per Sack of Cement		
		Water, gal.	Sand, lb.	Gravel, lb.
No. 1	7.60	4.2	163	258
No. 2	6.12	5.0	224	316
No. 3	5.12	6.2	292	368
No. 4	4.52	7.2	343	403
No. 5	4.20	8.0	373	428
No. 6[a]	6.04	5.8	256	285

[a] In Mix No. 6 each screen size of the coarse aggregate contained equal weights of crushed and uncrushed gravel. The fine aggregate contained 11 per cent by weight of crusher screenings and 89 per cent natural sand.

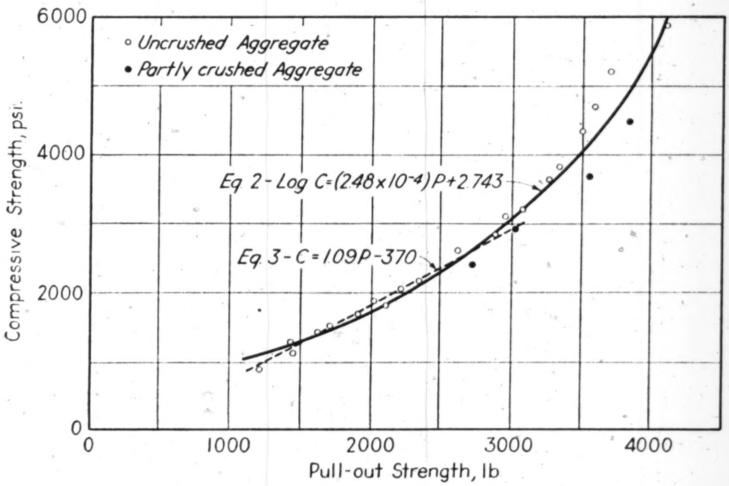


FIG. 2—Relationship of Pull-Out Strength to Compressive Strength.

Details of the method of making the pull-out test are shown in Fig. 1. The rod was gripped at a distance of about 10 in. from the face of the concrete by jaws in the movable head of the testing machine which travelled at the rate of 0.05 in. per min. when the machine was running idle. Failure occurred by the formation of a cone 4 to 6 in. in diameter extending to a point about midway in the length of the enlarged end. It will be noted that a spherical seat was provided in the bearing ring and that a thin asbestos gasket was used between the ring and the specimen. These provisions were made in order to reduce localized stresses.

DATA OF THE TESTS

The mix proportions and the grading of the aggregates are given in Tables I and II. The results of the strength tests are given in Table III. The relationship between pull-out strength and compressive strength is shown in Fig. 2.

TABLE III.—RESULTS OF STRENGTH TESTS.
(Each value is the result of an individual test.)

	Age 4 Days		Age 6 Days		Age 9 Days		Age 14 Days	
	P[a]	C[b]	P[a]	C[b]	P[a]	C[b]	P[a]	C[b]
MIX No. 1								
	2610[d]	3380[d]	3080	3360	3120	4870	3440	5640
	2900	3770	3240	4180	3320	5160	3570	5650
	3070	3810	3620	4400	3410	5230	3870	5940
	3550	3890	3640	4400	3700	5390	4030	6070
	3800	5160[d]	3940	4460	4380	5400	5600	6180
Average.....	3300	3820	3510	4360	3700	5210	4100	5900
v[c]..........	13.6	15.1	9.1	9.8	12.2	3.7	19.0	4.5
MIX No. 2								
	2480	2530	2760	3020	3000	2970[d]	3130	3960[d]
	2680	2750	2960	3120	3110	3610	3340	4400
	2910	2850	3070	3280	3200	3640	3530	4520
	3100	3010	3300	3450	3380	3660	3650	4940
	3300[d]	3130	3380	3820[d]	3640	3760	4300	5050
Average.....	2790	2850	3090	3220	3270	3670	3590	4730
v[c]..........	10.1	8.0	7.2	8.4	6.9	8.1	11.0	8.6
MIX No. 3								
	1780	1810	2200	2010	2280	2370	2700	2480
	1870	1870	2210	2100	2620	2500	2710	2810
	2110	1930	2320	2100	2660	2580	2760	3130
	2140	1940	2420	2270	2900	2760	2900	3380
	2200	2020	2600	2470	3360[d]	2930	3780	3780
Average.....	2020	1910	2350	2190	2620	2630	2970	3130
v[c]..........	8.1	3.7	6.3	7.4	13.0	7.5	13.8	14.4
MIX No. 4								
	1340	1060	1560	1530	1710[d]	1630	2020	1950
	1370	1130	1670	1530	1930	1670	2110	1980
	1470	1130	1760	1540	1940	1870	2400	2050
	1550	1260	1780	1560	2280	1910	2650	2170
	1670[d]	1340	1790	1600	2300	2030	2940	2270
Average.....	1430	1220	1710	1550	2110	1820	2420	2080
v[c]..........	8.2	8.0	5.1	5.4	11.1	18.5	14.1	5.8
MIX No. 5								
	1180	740	1360	1030	1560	1340	1630	1420
	1180	910	1420	1080	1570	1400	1730	1520
	1180	920	1450	1150	1650	1420	1900	1770
	1200	950	1480	1200	1650	1430	2000	1840
	1320	1060	1600	1290	1670	1470	2280	2020
Average.....	1210	920	1460	1150	1620	1420	1910	1710
v[c]..........	4.5	11.2	5.5	7.9	3.5	3.1	11.8	12.8
MIX No. 6								
	2260[d]	2140	2740	2480	2700[d]	2720[d]	3180[d]	4280
	2650	2340	3000	2940	3120	3580	3550	4420
	2670	2430	3030	3020	3670	3660	3620	4500
	2700	2530	3050	3150	3700	3700	4050	4550
	2860	2560	3300	3160	3750	3800	4120	4640
Average.....	2720	2410	3020	2950	3550	3690	3840	4480
v[c]..........	9.0	6.2	5.9	8.4	12.2	11.2	9.4	2.7

Grand Average, *v* (pull-out) = 9.6%, *v* (compression) = 8.4%.

[a] P = Pull-out strength in pounds.
[b] C = Compressive strength in psi.
[c] *v* = Coefficient of variation in per cent.
[d] Value omitted in computing average.

DISCUSSION

In computing average strength values in Table III a few results which deviate more than 15 per cent from the average were discarded. In a few instances results which were about 15 per cent low, when balanced by a result equally high, were retained because the average was not appreciably affected by doing so. In all, eight pull-out tests, or 7 per cent, and six compression tests, or 5 per cent of the total, were discarded as being "wild." The elimination of the "wild" results gave average values which were in better agreement with age-strength curves derived by the method of least squares.

TABLE IV.—VALUES OF COMPRESSIVE STRENGTH COMPUTED FROM PULL-OUT STRENGTHS COMPARED TO BEST VALUES OF COMPRESSIVE STRENGTH.

Mix	Age, days	Pull-out Strength, lb.	Best Value of Compressive Strength, psi.	Computed Compressive Strength, psi.					
				by Eq. 2			by Eq. 3		
				C	Deviation	Per cent Deviation	C	Deviation	Per cent Deviation
No. 1....	4	3330	3780	3710	−70	1.9			
	6	3510	4470	4110	+60	8.1			
	9	3700	5150	4580	−570	11.1			
	14	4100	5890	5770	−120	2.0			
No. 2....	4	2790	2720	2720	0	0	2650	−70	2.6
	6	3090	3300	3230	−70	2.1			
	9	3270	3900	3580	−320	8.2			
	14	3590	4540	4300	−240	5.3			
No. 3....	4	2020	1870	1750	−120	6.4	1830	−40	2.1
	6	2350	2280	2120	−160	7.0	2190	−90	3.9
	9	2620	2670	2470	−200	7.5	2490	−180	6.7
	14	2970	3090	3010	−80	2.5			
No. 4....	4	1430	1250	1250	0	0	1190	−60	4.8
	6	1710	1510	1470	−40	2.6	1490	−20	1.3
	9	2110	1800	1850	+50	2.8	1930	+130	7.2
	14	2420	2100	2200	+100	4.8	2270	+170	8.5
No. 5....	4	1210	910	1100	+190	20.9	950	+40	4.4
	6	1460	1170	1270	+100	8.5	1220	+50	4.3
	9	1620	1420	1400	−20	1.4	1400	−20	1.4
	14	1910	1700	1650	−50	2.9	1710	+10	0.6
No. 6....	4	2720	2360	2620	+260	11.0	2590	+230	9.7
	6	3020	3030	3110	+80	2.6	2930	−100	3.3
	9	3550	3700	4210	+510	13.8			
	14	3840	4430	4970	+540	12.2			
Average..................					±165	±6.4		±86	±4.3

Coefficients of variation, v, were computed on the basis of all tests, including those considered as "wild." The grand average coefficient of variation for pull-out tests was 9.6 per cent and for compression tests 8.4 per cent. This indicates that the pull-out test can be duplicated with nearly as great a degree of accuracy as the compression test.

The coefficient of correlation, r, using Pearson's product moment formula applied to average values of pull-out and compressive strengths, is 0.97. This indicates a very high degree of correlation between the two tests.

In a preliminary series of laboratory tests, the spherical-seated ring and asbestos gasket shown in Fig. 1 were not used. There was some warping of the side forms as well. In these tests the coefficient of correlation was found to be only 0.87. In general, pull-out strengths were considerably lower for a given compressive strength than in the tests reported in this paper.

The solid curve of Fig. 2 represents an equation computed by the method of least squares applied to the complete data It is of the form:

$$\log C = nP + k \ldots\ldots\ldots\ldots (1)$$

where:

C = compressive strength in pounds per square inch,
P = pull-out strength in pounds, and
n and k = constants.

For the particular conditions of this test, Eq. 1 may be written:

$$\log C = (2.48 \times 10^{-4})P + 2.743 \ldots (2)$$

The broken-line curve of Fig. 2 represents the following linear equation which was computed by the method of least squares applied to pull-out strengths of 3000 lb. and less:

$$C = 1.09P - 370 \ldots\ldots\ldots (3)$$

It is recognized that pull-out tests should be compared to the best values of compressive strength and that the observed compressive strengths were not necessarily the best values. Best values were computed from equations derived from age-strength relationships by the method of least squares.

Inspection of Fig. 2 shows that the pull-out results were more erratic in concrete of higher strength. In Table IV comparisons are given between compressive strength as computed from pull-out strength and from best values of compressive strength. The maximum deviation when computed by Eq. 2 was 570 psi. but for strengths not higher than 3500 psi. the maximum was 260 psi. When compressive strengths up to 3500 psi. were computed by Eq. 3 the maximum deviation was 470 psi. but for strengths not higher than 3000 psi. the maximum was 230 psi.

This indicates that considerable lack of precision is to be expected in concrete having compressive strength above about 3500 psi. Equation 3 is best suited for computing compressive strengths below about 3000 psi. and Eq. 2 for strengths above this value.

In these computations the specimens of mix No. 6, containing crushed aggregate, were included. Inspection of Fig. 2 indicates that pull-out strengths for this mix were slightly higher for corresponding compressive strengths than were found for the uncrushed aggregate, the indicated deviations being equivalent to about 200 psi. The use of a correction factor estimated for angularity probably would improve the precision of computed compressive strengths.

The data, therefore, indicate that in concrete of not over 3500 psi. the true compressive strength can frequently be estimated with greater precision by means of pull-out tests of bars embedded in the structure than by separately cast compression specimens.

APPLICATION ON THE JOB

The studies reported herein did not include pull-out tests of rods embedded in actual structures. It is contemplated that the bar would be inserted in a horizontal position through the forms and be fixed in place by methods similar to those used in the laboratory tests. The test would be made by attaching a dynamometer or gage-equipped hydraulic jack to the threaded end of the pull-out bar. It is obvious that the constants given in Eq. 2 and 3 will not be applicable unless provisions to prevent unequal bearing are made to an extent equivalent to those of the laboratory tests. The form in the region of the bar should be at least as nearly plane as that of plywood. The use of a thin gasket between the concrete and the testing device is recommended.

The test bars should be located with sufficient clearance from reinforcing steel, preferably not less than 3 in. Inconspicuous locations, such as the inner faces of beams and girders, could usually be selected for test. The holes left by the test could be patched with mortar.

It should be pointed out that this study did not include the effect of partial drying of the concrete. It is recommended, therefore, that if tests are made after wet curing has been discontinued, the concrete surrounding the test area be previously saturated with water.

Best results are obtained in concrete having a compressive strength of not over 3500 psi. The assurance, however, that strengths up to such a value have actually been attained will, in general, fulfill the needs outlined in the introduction.

CONCLUSIONS

Pull-out tests can be reproduced within limits that are nearly as close as for compression tests.

A high degree of correlation exists between pull-out and compression tests.

Data from laboratory tests indicate that the pull-out test can be applied to concrete in structures with less error in estimating actual compressive strengths that are not above about 3500 psi. than is often obtained through the use of test cylinders.

SOME PROPERTIES OF CONCRETE UNDER SUSTAINED COMBINED STRESSES

By C. Martin Duke[1] and Harmer E. Davis[1]

Synopsis

The paper presents the results of laboratory investigations on the creep of concrete under combined stresses. Most of the tests were conducted on 8 by 16-in. cylinders, using three different ratios of axial to lateral stress. In addition, some tubular specimens were tested in torsion. Supplementary tests were made to study the effect of pore pressure on strength of concrete under combined stresses.

A method is tentatively advanced for estimating the approximate magnitude of creep under combined stresses from the results of measurements of creep under simple axial compression. When applied to the results of the tests herein presented, the method gives estimated creeps which are reasonably close to the measured creeps during the first few weeks after loading. It is thought that changes in cement gel structure induced by the applied water pressure may be responsible for differences in estimated and measured creeps at later times.

During the past twenty years considerable information has been developed on the creep or plastic flow of concrete under axial compression and some information has been developed on creep or flow under axial tension. Relatively little work appears to have been done in connection with the creep of concrete under sustained triaxial loading. The tests described in this paper were conducted in the Engineering Materials Laboratory of the University of California, for the purpose of securing some data on the axial and lateral deformations which occur in concrete under sustained combined loadings.

The authors desire to acknowledge the continued and enthusiastic support of Prof. Raymond E. Davis, Director of the Engineering Materials Laboratory, University of California, in the planning and conduct of the studies on the creep of concrete under sustained load. Appreciation also is expressed to Prof. J. W. Kelly for his supervision of the tests on sustained torsional loading, and to Messrs. C. Bates, R. Cayot, A. Cooke, J. Geyer, K. Kettner, S. Lee, H. Louie, F. Poulsen, R. Woodbury, former students in the College of Engineering, for their very considerable contributions to the work of testing in a number of its phases.

Scope of Tests

The majority of the tests described herein were conducted on 8 by 16-in. concrete cylinders subjected to sustained triaxial loading. The object of these tests was to obtain the axial and lateral creep characteristics of concrete under various load combinations. Strain measurements were made in some cases both parallel and normal to the logitudinal axes of the test cylinders by means of electric strainmeters; in other cases (under simple axial load and under no load) longitudinal surface strains only were measured by means of a fulcrum-plate strain gage. The concretes were, in effect, in a saturated condition in these tests. The loads were applied 7 or 10 days after casting the concretes and were sustained for 2 to 3 months.

---

[1] Instructor in Civil Engineering and Associate Professor of Civil Engineering, respectively, University of California, Berkeley, Calif.

The detailed conditions of test for series 35 and 36, on the creep of concrete under sustained triaxial loading, are given in Table I. The tests of series 36 were made to provide a check on the findings of series 35 and are essentially a duplication of the earlier series. For the purpose of this paper, the results will be considered as those of a composite investigation. In this group of tests there were involved 13 test specimens, of which 7 were subjected to sustained load and 6 were used to indicate length changes due to causes other than load.

Supplementary to the tests of series 35, there was conducted a limited investigation of the strength of concretes under triaxial compression. These tests were made to provide some information on the relative strength of partially dry and saturated concretes as it may be affected by pore pressures. In these experiments there were tested to failure, at age 28 days, 128 3 by 6-in. cylinders. For each condition of test, several specimens were subjected to constant lateral pressure, while the axial load was increased to cause failure. The lateral pressures employed ranged from 0 to 900 psi. The specimens of one group were moist cured for 28 days, saturated at time of test, and in direct contact with

TABLE I.—SUMMARY OF TEST CONDITIONS FOR CREEP TESTS OF CONCRETE UNDER SUSTAINED TRIAXIAL LOADING. SERIES 35 AND 36.

Applied Stress, psi.[a]		Test Series[b]	Specimen	Age at Loading, days	Period over Which Load Sustained, days	Method of Strain Measurement			Storage[e]
						Axial		Lateral	
Axial	Lateral					Surface	Internal		
500	0	35	No. 2	7	99	F. P. Gage[c]	Strainmeter[d]	Strainmeter	Air at 95% R.H.
500	0	35	No. 3	7	99		...	...	Air at 95% R.H.
500	0	36	No. 9	10	63		Strainmeter	Strainmeter	Water
500	0	36	No. 10	10	65		...	...	Water
500	250	35	No. 1	7	99	...	Strainmeter	Strainmeter	Water
500	250	36	No. 8	10	66	...	...	Strainmeter	Water
250	250	36	No. 11	10	66	...	...	Strainmeter	Water
0[f]	0	35	No. 4, 5	..	..	F. P. Gage	...	F. P. Gage	Air at 95% R.H.
0	0	35	No. 6, 7	..	..	F. P. Gage	...	F. P. Gage	Water
0	0	36	No. 12, 13	..	..	F. P. Gage	...	...	Water

[a] Stress in 8 by 16-in. cylinders computed from applied loads.

[b] Same concrete mix proportions, but different lot of cement used in Series 35 and Series 36. See Table II for details.

[c] F. P. Gage = 10-in. fulcrum-plate or Whittemore-type strain gage applied to gage plugs cast in concrete on 3 gage lines 120 deg. apart around circumference of cylinder.

[d] Carlson electric strainmeter. See Fig. 1 for placement and leads.

[e] Storage temperature 70 F. All test specimens covered with rubber (29 gage, dam stock) jackets. Specimens of series 36 covered also with lead foil. All covering proved ineffective in preventing passage of moisture over period of tests.

[f] Control specimens, Nos. 4, 6, 12, 13, were 8-in. by 16-in. cylinders; Nos. 5 and 7 were 12-in. cubes.

the water in the testing chamber during loading. The specimens of the other group were moist cured for 21 days, stored in air of 50 per cent relative humidity for 5 days, and then coated with two coats of a heavy moisture-resistant lacquer. Details of the test conditions are summarized later in Table III in connection with discussion of the test results.

In addition to the principal series of tests on cylinders under triaxial loading, a number of exploratory experiments were carried out in which the applied loads induced primary or pure shear. The results of the most important group of these experiments, some tests on concrete tubes in torsion, are summarized briefly in this paper., Tubular specimens having an outside diameter of 9 in., a wall thickness of $1\frac{1}{2}$ in., and a length of $29\frac{1}{2}$ in. were subjected to torques which caused extreme fiber stresses in shear of 50 and 100 psi. Three tubes were tested in air at 95 per cent relative humidity and four in air at 50 per cent relative humidity. Details of the conditions of test are summarized later in Table IV in connection with discussion of the test results.

MATERIALS, APPARATUS, AND METHODS OF TESTING

Concrete mix data for the several series of tests are given in Table II.

TABLE II.—SUMMARY OF CONCRETE MIX DATA.

Test Series	Group	Cement	Aggregate	Aggregate-Cement Ratio, by weight	Water-Cement Ratio, by weight	Maximum Size of Aggregate, in.	Sand, per cent	Slump, in.
35	Sustained Compression (8 by 16-in. cylinders and 12-in. cubes)	Calaveras Type I	Niles sand and smooth Fair Oaks gravel	7.0	0.62	1½	38	2
	Compressive strength (3 by 6-in. cylinders)	Calaveras Type I	Niles sand and smooth Fair Oaks gravel	4.0	0.48	⅜	50	½
36	Sustained Compression (8 by 16-in. cylinders)	Santa Cruz Type I	Niles sand and smooth Fair Oaks gravel	7.0	0.62	1½	38	2
33	Sustained torsion (tubes 29½ in. long, 9 in. O.D., 6 in. I.D.)	Santa Cruz Type I	Antioch and Monterey Sands, Smooth Fair Oaks Gravel	5.6 4.7	0.53 0.50 0.50	¾	44	7 3 7

For the sustained load tests under triaxial compression, a special apparatus was designed, the principal features of which are shown schematically in Fig. 1. The container is a steel cylinder, sufficiently large to hold an 8 by 16-in. concrete cylinder under test. A special feature of the apparatus is a spun-brass sylphon bellows, which was used as a flexible seal around the lower end of the piston used to apply axial load. This seal obviated the necessity for a packing gland, and hence (1) permitted the practically free transmission of load from an external spring to the specimen (since the load required to deform the bellows for a considerable range was small compared with that of the load applied), and (2) eliminated the leakage which occurs over a long period of time with the ordinary packing gland, and presents a serious problem in tests of this sort.

During test, the axial load was sustained by means of a calibrated compressed helical car spring. The space surrounding the specimen within the container was filled with water, and pressure was applied to the water and sustained by compressed air in an auxiliary vessel or pressure dome. When necessary, compressed air from an outside source was admitted to the pressure dome.

In an attempt to prevent gain or loss of water from the concrete, the specimens in series 35 were covered with rubber jackets. Because these were found to be largely ineffective, in series 36 sheets of lead foil were laid on the surfaces of the concrete cylinders under the rubber jackets. Over a long period of time it was found that this expedient also was not entirely effective, owing to poor sealing at joints. Thus, the jacketing impeded but did not prevent the flow of moisture to or from the concrete.

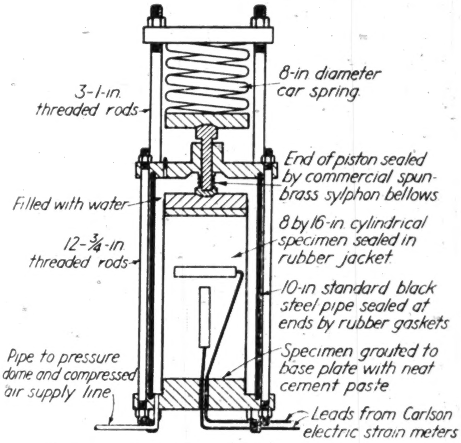

3-1-in. threaded rods
8-in diameter car spring
End of piston sealed by commercial spun-brass sylphon bellows
Filled with water
8 by 16-in. cylindrical specimen sealed in rubber jacket
12-¾-in. threaded rods
10-in standard black steel pipe sealed at ends by rubber gaskets
Specimen grouted to base plate with neat cement paste
Pipe to pressure dome and compressed air supply line
Leads from Carlson electric strain meters

FIG. 1.—Triaxial Loading Apparatus.

To the test cylinders subjected to axial load only, load was applied by calibrated compressed car springs in a rig composed of steel rods and plates. In series 35, the axially loaded cylinders were covered with rubber jackets and stored in air of 95 per cent relative humidity. In series 36, the axially loaded cylinders were covered with lead foil and rubber jackets and stored in an open tank of water.

Corresponding to the loaded test specimens of each series, control specimens were jacketed and maintained either in air at 95 per cent relative humidity or under water. All test specimens were maintained at a temperature of 70 F. The concretes were saturated at beginning of test.

Surface strain gage measurements and measurements by means of specially built, short gage length Carlson electric strainmeters were taken as indicated in Table I. The location of the internal strainmeters and the way in which the leads were conducted from the compression chamber are indicated in Fig. 1.

For the supplementary tests to determine strength of concrete under triaxial loading, the loading chamber consisted of the cylinder and plunger of an 8-in. diameter hydraulic jack. A test specimen was placed in the chamber of the jack. Axial load was applied through the piston of the jack by means of an ordinary testing machine. Lateral pressures were applied and maintained by means of a hand pump.

In the torsion tests, one end of a tube was fixed in position relative to the floor by braces and clamps. On the free end was clamped a steel band to which was fastened a lever. Weights on the end of the lever arm supplied a sustained load. The specimens rested on a smooth floor and could roll slightly as twisting took place. The angles of twist were measured by means of a specially made gradienter, which contained a level tube sensitive to 5 sec. of arc. The gradienter was applied to two collars 17 in. apart on each specimen to give the difference in rotation of the collars.

TEST RESULTS

The symbols to be used in connection with presentation of test results are defined as follows:

$\sigma_1, \sigma_2, \sigma_3$ = major, intermediate, and minor principal stresses respectively; in the tests on cylindrical specimens, σ_1 was the axial stress.

σ_A = axial stress in a cylinder under simple axial load.

τ = maximum shear stress in state of pure shear.

μ = Poisson's ratio.

Triaxial Creep Tests:

The results of the tests of series 35 on concrete cylinders subjected to sustained loads are summarized in Fig. 2. The diagrams show the total axial and lateral strains for both (*a*) an axial stress of 500 psi. ($\sigma_1 = 500$ psi.) and no lateral stress ($\sigma_2 = \sigma_3 = 0$), and (*b*) an axial stress of 500 psi. ($\sigma_1 = 500$ psi.) and a lateral stress of 250 psi. ($\sigma_2 = \sigma_3 = 250$ psi.).

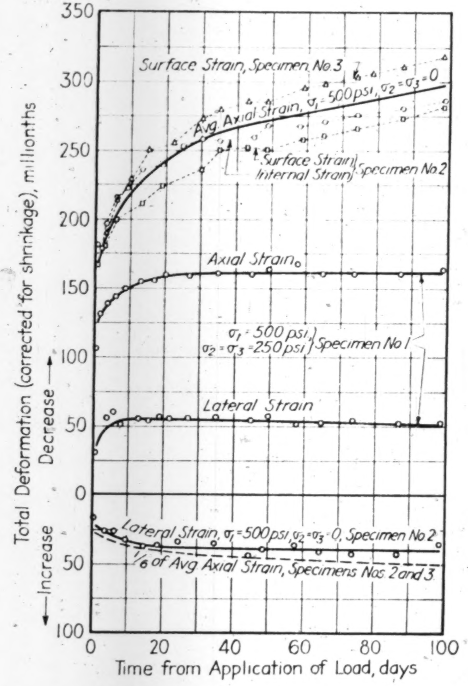


FIG. 2.—Axial and Lateral Strains Under Axial and Triaxial Loads—Series 35.

Specimens, 8 by 16-in. cylinders. Aggregate, sand and gravel. Fineness modulus = 5.67. Type I cement. Aggregate-cement ratio, $a/c = 7.0$ by weight. Water-cement ratio, $w/c = 0.62$ by weight. Curing, 7 days moist at 70 F. Age at loading 7 days. After loading, specimens 2 and 3 stored in air at 70 F. and 95 per cent relative humidity, specimen No. 1 stored under water at 70 F. Jackets, 29-gage rubber dam.

The observed deformations for specimens Nos. 2 and 3, which were stored in air, were corrected for shrinkage as determined from observations on corresponding unstressed control specimens. These control specimens indicated shrinkages of 50 millionths vertically and 60 millionths horizontally after 99 days of exposure under the ambient conditions. The water-stored control specimens showed no appreciable movements.

The difference in behavior of two companion specimens (Nos. 2 and 3), as measured by surface strains is indicated by the plotted points at the top of the figure. The difference between the surface and internal strain measurements for specimen No. 2 is also shown. The position of the curve representing the average axial strains for the simple axial load condition has been estimated.

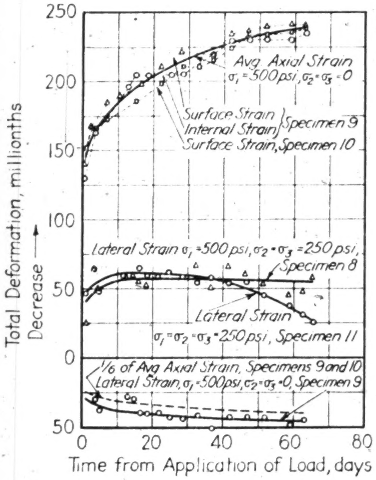


FIG. 3.—Axial and Lateral Strains Under Axial and Triaxial Loads—Series 36.

Specimens, 8 by 16-in. cylinders. Aggregate, sand and gravel. Fineness modulus = 5.60. Type I cement. Aggregate-cement ratio, $a/c = 7.0$ by weight. Water-cement ratio, $w/c = 0.62$ by weight. Curing, 10 days moist at 70 F. Age at loading, 10 days. Storage after loading, under water at 70 F. Jackets, lead foil and 29-gage rubber dam.

The results of the tests of series 36 are summarized in Fig. 3. The diagrams show total axial and lateral strains for (*a*) $\sigma_1 = 500$ psi., $\sigma_2 = \sigma_3 = 0$; and lateral strains for (*b*) $\sigma_1 = 500$ psi., $\sigma_2 = \sigma_3 = 250$ psi.; and (*c*) $\sigma_1 = \sigma_2 = \sigma_3 = 250$ psi. All specimens in this series were stored under water, and the growth of the unstressed control specimens was of negligible magnitude.

Strainmeter readings on some of the specimens gave rather erratic results during the application of load, although all later readings gave results which checked closely with surface strains and gave consistent comparisons between the several conditions of loading. Therefore, in presenting the data, there have been shown only the *total* strains beginning one day after loading.

From a general examination of the data shown in Figs. 2 and 3, the following observations are made:

1. Under the axial load alone, creep occurs laterally as well as axially, and, based on total strains, the Poisson's ratio effect under sustained load was about $\frac{1}{6}$ for these tests.
2. For comparable testing conditions, the creep characteristics of the concretes in both series of tests were practically identical, as may be seen by comparing the data for specimens 1 and 8, for which $\sigma_1 = 500$ psi. and $\sigma_2 = \sigma_3 = 250$ psi. From this it is concluded that the creep characteristics were not appreciably influenced by whatever differences may have existed in the composition of the cements. Both cements were A.S.T.M. type 1.[2]
3. The axially loaded specimens of series 35 (Fig. 2) exhibited appreciably greater creep longitudinally and slightly less creep laterally than the corresponding specimens of series 36 (Fig. 3). This behavior is attributed primarily to the difference in moisture conditions rather than to differences in the cement. As previously indicated, the axially loaded specimens of series 35 were subject to some degree of drying, while all others were maintained fully saturated.
4. For the concrete cylinders subjected to the same axial load, existence of a lateral pressure caused a marked decrease in longitudinal strain and caused lateral compressive strains exceeding the lateral extensions due to the Poisson's ratio effect under axial load only.
5. Under equal triaxial pressures (hydrostatic loading), the total strains ceased increasing and began to decrease after about three weeks under load.

Prediction of Creep-Time Relationship for Triaxial Stress:

Based upon an analysis of the data, the following procedure is tentatively proposed for estimating the aproximate magnitude of creep under triaxial stresses from the results of tests to determine creep under simple axial compression. The assumptions involved are:

1. The total strains (elastic + creep) are proportional to the magnitudes of the sustained stresses. Earlier work on creep of concrete under sustained axial load has indicated that this is a fair approximation for stresses in the working range, and has led to the concept of a "sustained" modulus of elasticity.
2. The Poisson's ratio effect is constant and the ratio holds for total strains under sustained stress as well as for strains which occur under relatively rapid loading. The tests herein reported as well as scattered previously obtained data, indicate that this condition is closely satisfied (see Figs. 2 and 3).

The effect of these assumptions is to permit the use of the basic equations of elasticity for determining the strain-time curve for any state of sustained stress. From these considerations it may be shown that the ratio, R_A, of the axial strain in a cylinder under triaxial stress to the axial strain in a cylinder subject to simple axial stress is:

$$R_A = \frac{\sigma_1}{\sigma_A} - \mu \frac{\sigma_2}{\sigma_A} - \mu \frac{\sigma_3}{\sigma_A}$$

The notation is as defined previously.

If $\sigma_A = 500$ psi., $\sigma_1 = 500$ psi., $\sigma_2 = \sigma_3 = 250$ psi., $\mu = \frac{1}{6}$, then $R_A = \frac{5}{6}$;

---

[2] See Standard Specifications for Portland Cement (C 150 - 42), 1942 Book of A.S.T.M. Standards, Part II, p. 1.

that is, the axial strains at any given time after loading, in a cylinder under the given triaxial stresses, are $\frac{5}{6}$ of those of the axially loaded cylinder with which the comparison is made. Equations may be similarly written for other conditions. For example, the lateral strain ratio, R_L, for the triaxial stress condition above specified is $\frac{1}{4}$. The axial or lateral strain ratio, $R_A = R_L$, for hydrostatic pressure, $\sigma_1 = \sigma_2 = \sigma_3 = 250$ psi. ($\sigma_A = 500$ psi.) is $\frac{1}{3}$.

In Fig. 4, the broken lines which have been plotted represent these ratios with respect to the axial strains in an axially loaded cylinder stored under water, and therefore represent *estimated* strains for the stated triaxial load conditions. Their approximation to the corresponding observed strains is reasonably close for the first month or so under load, and in consideration of the errors involved in analysis where data of this sort are used, the estimated values would probably be good enough for practical purposes in a number of situations.

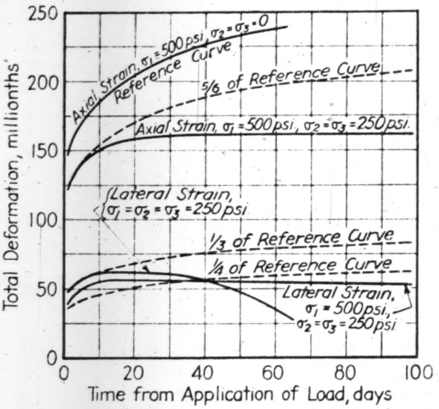


FIG. 4.—Comparison of Observed and Computed Strains Under Axial and Triaxial Loads.

Theoretical curves are drawn on assumption that Poisson's ratio is 1/6 for both elastic and creep strains.

One outstanding fact to be noted, in a comparison between the observed and computed strains plotted in Fig. 4, is that the observed strains tend continuously to become less than the strains estimated from the axial load data, and the divergence becomes greater with time under load. The specimen subject to hydrostatic load, as indicated previously, actually began to expand after about three weeks under load.

It is of interest to speculate on the cause of this behavior. In the concept of the gradual development of pore pressures within the concrete, considered to be, in effect, a granular mass, lies one possible explanation.

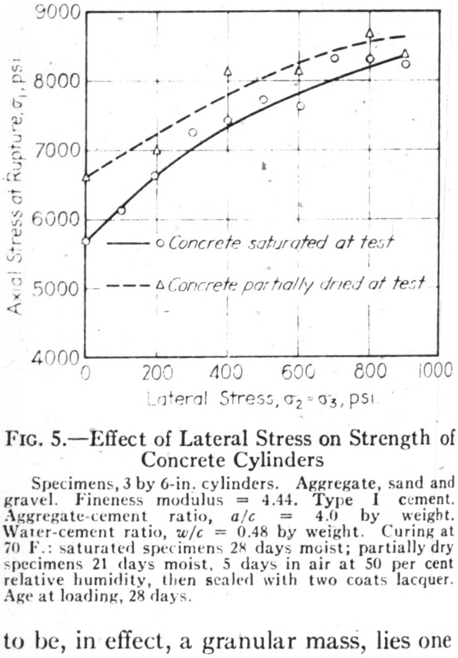


FIG. 5.—Effect of Lateral Stress on Strength of Concrete Cylinders

Specimens, 3 by 6-in. cylinders. Aggregate, sand and gravel. Fineness modulus = 4.44. Type I cement. Aggregate-cement ratio, a/c = 4.0 by weight. Water-cement ratio, w/c = 0.48 by weight. Curing at 70 F.: saturated specimens 28 days moist; partially dry specimens 21 days moist, 5 days in air at 50 per cent relative humidity, then sealed with two coats lacquer. Age at loading, 28 days.

Another possible explanation lies in the concept that the volumetric equilibrium of the cement-gel is a function of what may be loosely termed the "ambient moisture back pressure." Thus, if the stress due to load is sufficiently high, water is expelled from the gel structure of a loaded concrete mass, and the mass will decrease in volume until the vapor pressure of the surroundings plus the forces of adsorption on the water in the pores of the gel, due to molecular attraction, are in equilibrium with the forces tending to cause flow of the water. The greater the back pressure of the external water supply the greater the potential gel volume at equilibrium, and also the less rapid the expulsion of water from the gel mass under any given mechanical pressure applied to the mass. It is then conceivable further that as water under sufficiently high pressure permeates a mass already consolidated to a volume smaller than the equilibrium volume for the given back pressure, expansion will take place.

TABLE III.—STRENGTH OF 3 BY 6-IN. CYLINDERS UNDER TRIAXIAL LOADING.

Lateral Stress psi.	Moisture Condition of Specimen at Test[a]	Number of Batches Represented	Number of Specimens Tested	Number of Specimens Discarded[b]	Average Axial Rupture Stress, psi.	Difference
0	Saturated	9	19	3	5690	
	Partially dry	6	8	2	6610	920
100	Saturated	4	8	3	6130	
192	Saturated	1	5	1	6630	
200	Partially dry	3	5	0	7000	370
300	Saturated	5	14	5	7250	
400	Saturated	3	13	3	7420	
	Partially dry	4	8	3	8130	710
500	Saturated	4	12	3	7720	
603	Saturated	1	4	1	7630	
600	Partially dry	2	6	0	8130	500
700	Saturated	4	8	2	8320	
800	Saturated	2	4	0	8300	
	Partially dry	2	4	0	8670	370
900	Saturated	2	5	1	8220	
	Partially dry	2	5	1	8380	160

[a] See Fig. 5 for details.
[b] Due to large deviation from mean.

Triaxial Strength Tests:

In Table III and Fig. 5 are shown the results of rupture tests under triaxial compressive stress on 3 by 6-in. concrete cylinders 28 days old. At time of test, 92 of the specimens were saturated and 36 were partially dry.

Based on the material in Table III and Fig. 5, the following observations are made:

1. Application of lateral stress increased the axial rupture stress by about $2\frac{1}{2}$ times the amount of the lateral stress. This ratio is roughly the same for saturated and partially-dry specimens.

2. Axial strength under no lateral pressure was greater for the partially dry than for the saturated specimens, even though the saturated specimens had the advantage of 7 extra days of moist curing (see Fig. 5). The difference in strength here observed seems to decrease slightly with increasing lateral pressures as indicated by the curves in Fig. 5 and the values in the last column of Table III.

TABLE IV.—CREEP IN SHEAR AFTER 50 DAYS UNDER TORSIONAL LOADING.

Shear Stress in Extreme Fiber psi.[a]	Specimen	Storage	Mix[b]		Observed Shear Strain, millionths of radians		
			$\frac{w}{c}$	$\frac{a}{c}$	Elastic	Creep	Total
100	No. 1	70 F. Air at 95% R.H.	0.53	5.6	52	72	124
100	No. 2		0.50	5.6	35	82	117
100	No. 3		0.50	4.7	50	14	64
50	No. 4	70 F. Air at 50% R.H.	0.53	5.6	92	240	332
50	No. 5		0.50	5.6	42	95	137
50	No. 6		0.50	4.7	70	35	105
100	No. 7		0.50	5.6	80	280	360

[a] Computed from conventional torsion formula. Loads applied at age 7 days.
[b] Fineness modulus = 4.80. See Table I for slumps.

A possible explanation of the difference in strength of saturated and partially dry specimens lies in the supposition that a state of triaxial stress exists in a saturated specimen under no applied lateral pressure. Rapid application of axial compressive stress may induce pressure in the pore water and a consequent lateral tension in the concrete. Thus a specimen with little or no pore water, but of the same mix and curing, might be expected to possess higher resistance to purely axial load. When sufficient lateral pressure to overcome the lateral tension has been applied to a saturated specimen, it would be expected that the axial strength would be the same as the axial strength of a partially dry specimen under no lateral stress. Beyond this point, increase in lateral pressure would cause the same increase in axial strength in both partially dry and saturated specimens.

Torsional Creep Tests:

Results of sustained torsion tests on seven concrete tubes are shown in Table IV. Load was applied at age 7 days, and the shear strains are shown for age 57 days.

Examination of Table IV leads to the following comments:

1. Shear creep was greater in dryer specimens and was increased by increase in stress, water-cement ratio, or aggregate-cement ratio. Except for the observed increase with aggregate-cement ratio, which may be in error, shear creep appears to have the same general properties as creep under tensile or compressive stresses.

2. The numerical value of shear creep was of the order of twice the compressive creep that would have occurred under a compressive stress of the same magnitude as the applied shear stress. This permits an application of the method proposed for estimating the approximate magnitude of creep under triaxial stress, for a state of pure shear may be created by equal, perpendicular direct stresses. For example, if $\sigma_A = 100$ psi., $\tau = 100$ psi., $\mu = \frac{1}{6}$, the shear-strain ratio is given as

$$R_S = 2(1 + \mu)\frac{\tau}{\sigma_A} = 7/3;$$

that is, the shear strain at any given time after loading is estimated to be about twice the axial compressive strain in the axially-loaded cylinder with which the comparson is made.

THE EFFECT OF DISCONTINUITIES OF THE NATURAL FREQUENCY OF BEAMS

BY PHILIP G. KIRMSER[1]

SYNOPSIS

It has frequently been found that the correlation between loss in modulus of rupture and loss in modulus of elasticity as determined by the dynamic method is not very good.

Since the poorest correlation has occurred for beams with cracks, the effects of changes in cross-section and changes of material on the natural frequency were studied by application of Rayleigh's method for determining the natural frequency to two special cases:

1. A beam with one crack of varying widths and depths at the center
2. A beam of many sections.

The theoretical treatment was followed by experimental verification of the theory, using cast iron beams machined to size.

It was found that the effect of a crack on the natural frequency is almost negligible, and that for a many-section beam satisfying certain conditions the frequency is the same as that of a beam of uniform cross-section with identical average properties.

The results can be applied to the interpretation of the behavior of concrete beams subjected to accelerated tests, and indicate that a loss in modulus of elasticity determined by means of vibrations always indicates deterioration, though the type and extent of this deterioration are not certain.

In the past few years the modulus of elasticity determined by means of vibrations has been used as a measure of deterioration of concrete beams subjected to accelerated tests of various types (**1, 2, 3, 4, 5, 6**).[2]

The deterioration appears to be of two main types:

1. That characterized by weakening of the cement paste, the bond, or the aggregate, or combinations of these failures. Such deterioration is usually encountered in freezing-and-thawing tests.

2. That characterized by the development of a few cracks. This type is often encountered in wetting-and-drying tests.

Attempts have been made to correlate the loss in modulus of elasticity determined by the natural frequency method with other properties, notably the loss in modulus of rupture (**3, 5**). The correlations obtained have not always been very good, the correlation being poorest for beams with type 2 deterioration, and those made of mortar. The best correlations were obtained in the case of beams with type 1 deterioration. Since largest discrepancies occur for the deterioration characterized by a few cracks, it is well to investigate the effect of cracks of various numbers, depths, and thicknesses on the natural frequency of a free-free beam. Of the methods of calculation available for this problem, which are direct calculation from the differential equation, the Stodolá method, the Rayleigh method, and its modification the Ritz method, the most practical is the Rayleigh method (**7, 10**).

---

[1] Instructor, Kansas State College of Agriculture and Applied Science, Manhattan, Kans.

[2] The boldface numbers in parentheses refer to the reports and paper appearing in the list of references appended to this paper, see p. 904.

In order to simplify the problem, the case of a free-free beam with one crack of varying width and depth at the center will be considered first. The potential energy of a deflected beam is given by:

$$\text{Pot} = \frac{1}{2}\int_0^l EI\left(\frac{\delta^2 y}{\delta x^2}\right)^2 dx \ldots\ldots (1)$$

and its kinetic energy by:

$$\text{Kin} = \frac{1}{2}\int_0^l \frac{A\gamma}{g}\left(\frac{\delta y}{\delta t}\right)^2 dx, \ldots\ldots (2)$$

where:

E = modulus of elasticity,
I = moment of inertia,
l = length of beam,
A = area of cross-section,
γ = weight per unit volume,
g = acceleration of gravity,
y = ordinate of dynamic deflection curve,
x = abscissa, length along beam, and
t = time.

Since energy must be conserved, the maximum potential energy must be equal to the maximum kinetic energy, or:

$$\frac{1}{2}\int_0^l \frac{A\gamma}{g}\left(\frac{\delta y}{\delta t}\right)^2 dx = \frac{1}{2}\int_0^l EI\left(\frac{\delta^2 y}{\delta x^2}\right)^2 dx \ldots (3)$$

If the vibration is harmonic,

$$\left(\frac{\delta y}{\delta t}\right)_{\max.} = \omega y \ldots\ldots\ldots\ldots (4)$$

where ω is the frequency in radians per sec. and y is the dynamic deflection curve at its greatest deflection, and Eq. 3 becomes:

$$\frac{1}{2}\int_0^l \frac{A\gamma}{g}\omega^2 y^2\, dx = \frac{1}{2}\int_0^l EI\left(\frac{d^2 y}{dx^2}\right)^2 dx \ldots (5)$$

which can be solved for ω, and thus for the frequency f, since:

$$f = \frac{\omega}{2\pi} \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

The difficulty with this method is that $y(x)$ is usually not known. If the dynamic deflection curve is known, the solution for f is exact. The accuracy of this method depends, then, on the accuracy with which y is known.

An excellent approximation in most cases is that the dynamic deflection curve is the same as the static deflection curve. The static deflection curve can be calculated conveniently by the moment area method (**8**). The beam is taken as being simply supported at the ends, as in Fig. 1. With the axes located at the midpoint of the beam, the moment equation is:

$$M = \frac{wl^2}{8} - \frac{wx^2}{2} \ldots\ldots\ldots\ldots (7)$$

where:

M = bending moment, and
w = weight per unit length.

The $\frac{M}{EI}$ diagram for this beam is given in Fig. 2. The deflection equation for this beam becomes:

$$y = \int_0^R \frac{M}{EI}(R - x)\, dx = \frac{1}{EI}\int_0^R \left(\frac{wl^2}{8} - \frac{wx^2}{2}\right)^2 (R - x)\, dx \ldots (8)$$

where:

x = variable distance along the beam, and
R = abscissa for which y is the deflection.

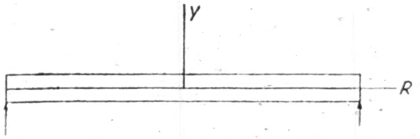


FIG. 1.—Beam Simply Supported at Ends.

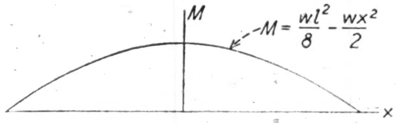


FIG. 2.—Moment Diagram for Simply Supported Beam.

If there is a crack at the center of the beam, the expression for the bending moment Eq. 7 will not be changed, since the weight of the beam is not changed. The $\frac{M}{EI}$ diagram, however, will appear as that of Fig. 3. The center portion *adg* of the curve is not known definitely since the stress distribution around the crack is not known. This portion is replaced by curve *bcef* of an equal area, having the width $c\Delta$ *where c is a proportionality* factor. Correspondingly, the deflection equation is given by

$$y = \int_0^R \frac{M}{EI} (R - x)\, dx + \frac{c\Delta}{2} \left(\frac{M_{R=0}}{E_c I_c} - \frac{M_{R=0}}{EI} \right) R \,..(9)$$

where:

Δ = width of crack,
$E_c I_c$ = stiffness at the crack,
EI = stiffness of beam other than at the crack, and
$M_{R=0}$ = moment as a function of R.

The integration of Eq. 9 gives:

$$y = \frac{1}{EI} \left[\frac{wl^2 R^2}{16} - \frac{wR^4}{24} \right] + \frac{c\Delta wl^2}{16} \left(\frac{1}{E_c I_c} - \frac{1}{EI} \right) R \,..(10)$$

Assuming that y is a good approximation for the dynamic deflection curve, the potential energy contained in the beam at maximum deflection is:

$$\text{Pot} = 2 \left[\frac{1}{2} \int_{\frac{c\Delta}{2}}^{\frac{l}{2}} \frac{1}{EI} \left(\frac{wl^2}{8} - \frac{wR^2}{2} \right)^2 dR \right] + \frac{c\Delta M_{R=0}^2}{2\, E_c I_c} \,...(11)$$

Integrating Eq. 11 and neglecting terms of higher order, the expression for the potential energy becomes:

$$\text{Pot} = 0.004167\, w^2 l^5 \left(\frac{1}{EI} \right) + \frac{w^2 l^4 c\Delta}{2(64)} \left(\frac{1}{E_c I_c} - \frac{1}{EI} \right) ...(12)$$

The expression for the kinetic energy of the beam when the potential energy is zero is

$$\text{Kin} = \frac{A\gamma\omega^2}{g} \int_0^{\frac{l}{2}} \left[\frac{wl^2 R^2}{16EI} - \frac{wR^4}{24EI} + \frac{c\Delta wl^2}{16} \left[\frac{1}{E_c I_c} - \frac{1}{EI} \right] R + \theta \right]^2 dR \,..(13)$$

where θ is the vertical displacement of the deflection equation, since the beam is not pin ended and the deflection curve must be displaced vertically so that the nodes are no longer at the ends of the beam ($\theta = O$ for a pin-ended beam). The value of θ for a free-free beam will

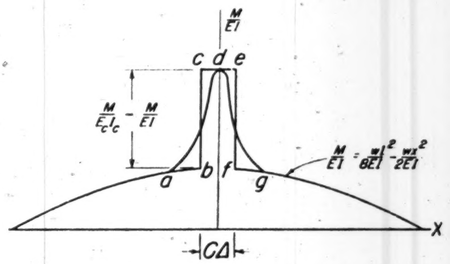

$\frac{M}{EI}$
c d e
$\frac{M}{E_c I_c} - \frac{M}{EI}$
$\frac{M}{EI} = \frac{wl^2}{8EI} - \frac{wx^2}{2EI}$
a b f g
X
$c\Delta$

FIG. 3.—$\frac{M}{EI}$ Diagram for Beam with Crack.

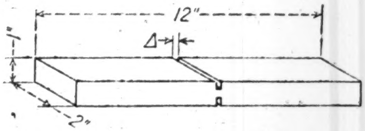


FIG. 4.—Beam With Crack at Center.

be such that the kinetic energy will be a minimum.

Equation 13, on integration and minimizing, becomes

$$\mathrm{Kin} = \frac{A\gamma\omega^2}{g}[0.010417\,k^2l^3 + 0.01042\,akl^4 + 0.00278\,a^2l^5 + 0.002083\,bkl^6 + 0.001190\,abl^7 + 0.0001389\,b^2l^9] \quad \text{..(14)}$$

where:

$$a = \frac{wl^2}{16EI},$$

$$b = -\frac{w}{24EI},$$

$$k = \frac{c\Delta wl^2 m}{16}, \text{ and}$$

$$m = \frac{1}{E_c I_c} - \frac{1}{EI}.$$

Now, on equating Eq. 12 to Eq. 14, solving for f, and simplifying,

$$f = \frac{\omega}{2\pi} = \frac{16}{2\pi l}\sqrt{\frac{g\left(0.004167\ EI + \dfrac{c\Delta m\overline{EI}^2}{2(64)l}\right)}{w(0.010417\ c^2\Delta^2 m^2\overline{EI}^2 + 0.00903\,c\Delta lmEI + 0.002048\,l^2)}} \quad \text{.....(15}$$

For the special case of a cast iron beam, 1 by 2 by 12 in., vibrated flatwise, where the beam has the following properties:

E = 16,650,000 psi. initial tangent modulus,
γ = 0.258 lb. per cu. in.
g = 386.04 in. per sec., per sec.

and where the crack extends from the top and bottom only (see Fig. 4), Eq. 15 reduces to:

$$f = 9668.9\sqrt{\frac{0.004167 + 0.00065104\,c\Delta\left(\dfrac{1}{d_c^3} - 1\right)}{0.010417\,c^2\Delta^2\left(\dfrac{1}{d_c^6} - \dfrac{2}{d_c^3} + 1\right) + 0.10835\,c\Delta\left(\dfrac{1}{d_c^3} - 1\right) + 0.294912}} \quad \text{..(16)}$$

where d_c is the depth of the beam at the crack.

Equation 16 is plotted for various values of Δ and d_c in Fig. 10 with $c = 5$. The frequency for the second mode of vibration will be the same as for a uniform beam without the crack at the center, since the crack occurs at a node which is an inflection point for the second mode of vibration.

In order to check the theory, a cast iron beam was made by milling a bar of cast iron to 1 by 2 by 12 in. The dimensions were accurate to 0.001 in. This beam was vibrated on the usual dynamic modulus apparatus to determine the modulus of elasticity of the cast iron.

A crack $\frac{1}{16}$ in. wide and $\frac{1}{8}$ in. deep was then milled from one side of the beam, the dimensions again being accurate to 0.001 in. The beam was then vibrated as a free-free beam with supports $2\frac{1}{2}$ in. from each end, and the driver $4\frac{1}{2}$ in. from one end. The frequencies at resonance were determined for the first and second modes of vibration. A crack $\frac{1}{8}$ in. deep and $\frac{1}{16}$ in. wide was then milled from the other side, and the procedure repeated until the beam was $\frac{1}{4}$ in. thick at the crack. The results are given in Table I, and in Fig. 10.

Equation 15 can be applied to other more complicated cases. If the crack, for example, is so narrow that on part of the down stroke the upper part takes compression, the vibration will not be harmonic, but the frequency can still be calculated.

If part of the crack can take compression but not tension, the I_c is larger than if there is no interference, and hence the effect of the crack is less than if there were no interference. The effect of the crack with interference, then, is the same as the effect of a crack of lesser depth.

If the interference is for only part of the cycle, part of the cycle will occur with $I_c = \frac{1}{12} bd_c^3$ where d_c is the depth of the beam at the crack, and part of the cycle will occur with $I_{c1} = \frac{1}{12} bd_{c1}^3$ where d_{c1} is the depth of the beam at the crack plus the depth of the beam that can take compression. The time for each portion of the cycle to take place can be calculated, and the results added to give the period for the beam with a crack that is so narrow that interference occurs on part of the cycle.

TABLE I.—EXPERIMENTAL FREQUENCY OF A HOMOGENEOUS BEAM WITH ONE $\frac{1}{16}$-IN. WIDE CRACK AT THE CENTER.

Depth of Crack, $1-d_c$ in.	Frequency, f, cycles per sec.			
	First mode		Second mode	
	Experimental	Calculated[a]	Experimental	Calculated[b]
0	1130	1149	2953	2980
⅛	1117	1130	....	2980
¼	1090	1100	2957	2980
⅜	1023	1040	2930	2980
½	928	945	2930	2980
⅝	746	760	2930	2980
¾	578	495	2930	2980
⅞	...	189	....	....

[a] From Eqs. 1 to 16. By slide rule.
[b] By method of Goens (9).

If the beam has no crack, but has a narrow section of material of different modulus and density, Eq. 15 can still be applied. E_cI_c will then be the stiffness of this narrow section of material.

For a beam of many sections, the Rayleigh method is the only practical method available. Consider a beam of length $2nl$ made up of repeating lengths $2l$. For such a beam the stiffness and density functions can be expanded into Fourier series. The conditions for expansion into a Fourier series are so broad that any reasonable beam can be treated in this manner.

$$\text{Let}\quad EI(x) = b_0 + b_1 \cos\frac{\pi x}{l} + \cdots$$

$$+ a_1 \sin\frac{\pi x}{l} + a_2 \sin\frac{2\pi x}{l} + \cdots \qquad (17)$$

$$\text{and}\quad m(x) = m_0 + m_1 \cos\frac{\pi x}{l} + \cdots$$

$$+ n_1 \sin\frac{\pi x}{l} + n_2 \sin\frac{2\pi x}{l} + \cdots \qquad (18)$$

where $m = \dfrac{A\gamma}{g}$.

For a free-free beam, a good approximation for the dynamic deflection curve is:

$$y = A_1\left(\sin\frac{\pi x}{2nl} - \theta\right) \ldots\ldots (19)$$

Substituting Eq. 19 into Eq. 1, the potential energy at maximum deflection is:

$$\text{Pot} = \frac{1}{2}\int_0^{2nl}\left(b_0 + b_1\cos\frac{\pi x}{l} + \cdots\right.$$

$$\left. + a_1 \sin\frac{\pi x}{l} + \cdots\right) A_1^2\left(\frac{\pi}{2nl}\right)^4 \sin^2\frac{\pi x}{2nl}dx \,.\,(20)$$

The kinetic energy becomes:

$$\text{Kin} = \frac{1}{2}\omega^2\int_0^{2nl}\left(m_0 + m_1\cos\frac{\pi x}{l} + \cdots\right.$$

$$\left. + n_1 \sin\frac{\pi x}{l} + \cdots\right) A_1^2\left(\sin\frac{\pi x}{2nl} - \theta\right)^2 dx \,.\,.\,(21)$$

On differentiating Eq. 21 and setting the derivative to zero, it is found that $\theta = \dfrac{2}{\pi}$ gives the minimum kinetic energy.

In order to evaluate Eq. 20 and Eq. 21, it is necessary to evaluate integrals of the following types:

$$\int_0^{2nl} b_j \cos\frac{j\pi x}{l}\sin^2\frac{\pi x}{2nl}dx = 0 \ldots\ldots\ldots\ldots (22)$$

$$\int_0^{2nl} a_j \sin\frac{j\pi x}{l}\sin^2\frac{\pi x}{2nl}dx = 0 \ldots\ldots\ldots\ldots (23)$$

$$\int_0^{2nl} m_j \cos\frac{j\pi x}{l}\sin\frac{\pi x}{2nl}\,dx = \frac{-4nlm_j}{(4n^2j^2-1)\pi} \quad (24)$$

$$\int_0^{2nl} n_j \sin\frac{j\pi x}{l}\sin\frac{\pi x}{2nl}\,dx = 0. \ldots\ldots\ldots\ldots (25)$$

$$\int_0^{2nl} m_j \cos\frac{j\pi x}{l}\,dx = 0 \ldots\ldots\ldots\ldots (26)$$

$$\int_0^{2nl} n_j \sin\frac{j\pi x}{l}\,dx = 0 \ldots\ldots\ldots\ldots (27)$$

Now, on equating Eq. 20 to Eq. 21:

$$\omega^2 = \frac{\left(\frac{\pi}{2nl}\right)^4 \int_0^{2nl} b_0 \sin^2\frac{\pi x}{2nl}\,dx}{\left[\int_0^{2nl} m_0 \sin^2\frac{\pi x}{2nl}\,dx - \int_0^{2nl} m_0\frac{4}{\pi}\sin\frac{\pi x}{2nl}\,dx + \sum_1^{\infty}\frac{4nlm_j}{(4n^2j^2-1)\pi} + \frac{4}{\pi^2}\int_0^{2nl} m_0\,dx\right]} \ldots (28)$$

Upon simplification, this becomes:

$$\omega^2 = \frac{\left(\frac{\pi}{2nl}\right)^4 b_0}{\left(\frac{\pi^2 - 4^2 + 8}{\pi^2}\right) m_0 + \sum_1^{\infty}\frac{4m_j}{(4n^2j^2-1)\pi}} \quad (29)$$

which for large values of *n* and *j* reduces to:

$$\omega^2 = \frac{\left(\frac{\pi}{2nl}\right)^4 b_0}{\left(\frac{\pi^2 - 8}{\pi^2}\right) m_0} \ldots\ldots\ldots (30)$$

In other words, the only terms of the Fourier series remaining are b_o and m_o which represent the average values of the functions $EI(x)$ and $\frac{A\gamma}{g}(x)$.

From Eq. 30 the frequency is found to be:

$$f = \frac{\omega}{2\pi} = \sqrt{\frac{\pi^2}{\pi^2-8}}\left(\frac{\pi}{2nl}\right)^2\frac{1}{2\pi}\sqrt{\frac{(EI)_{\text{avg.}}g}{(A\gamma)_{\text{avg.}}}}$$

$$= \frac{22.6}{2\pi L^2}\sqrt{\frac{(EI)_{\text{avg.}}g}{(A\gamma)_{\text{avg.}}}} \ldots (31)$$

where $L = 2nl$, the length of the beam.

This is the same as the expression for the frequency of a beam of uniform cross-section whose stiffness and density have the average values for the beam with many sections.

Equation 31 cannot be looked upon as being exact because of the three assumptions involved in its derivation:

1. The stiffness and density functions can be given in terms of Fourier series. This is very exact.

2. The dynamic deflection curve is given by $y = A_1(\sin\frac{\pi x}{2\ nl} - \frac{2}{\pi})$. This assumption will not hold if the beam is composed of sections radically different in size, but is a fairly good approximation if the variations are not too great. The exact equation for a beam of uniform cross-section is, for example

$$= \frac{22.4}{2\pi L^2}\sqrt{\frac{EIg}{A\gamma}}$$

as compared with:

$$f = \frac{22.6}{2\pi L^2}\sqrt{\frac{EIg}{A\gamma}}$$

Obtained from the above assumption (10).

3. Each section of the many-section beam acts as a beam. If the sections differ in size by sudden jumps this assumption is not exact. This is equivalent to assuming a stress distribution in the beam.

In order to check this theory, a beam of cast iron was milled successively into the shapes indicated in Figs. 5 to 8. For each shape, the beam was vibrated in two positions as a free-free beam supported at the nodes:

(*a*) With the plane surface horizontal, with the plane of vibration vertical, and

(*b*) With the plane surface vertical, with the plane of vibration vertical.

The values of E were then calculated from the experimental frequency by using Eq. 31 and assuming that the beam was of the minimum constant cross-section loaded by the projections. This calculated value was compared with the value determined from the solid bar of Fig. 5 by actually vibrating it. The comparison appears in Table II.

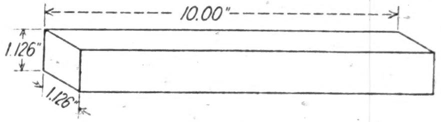


FIG. 5.—Section A.

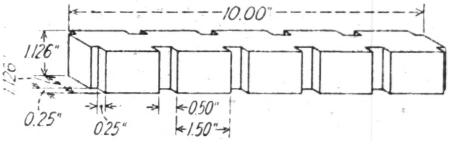


FIG. 6.—Section B.

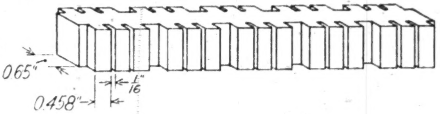


FIG. 7.—Section C.

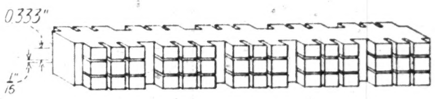


FIG. 8.—Section D.

It is apparent from the behavior of the various beams that assumption 3 is the most inaccurate.

The assumption made was that the projections acted as weights on a beam of uniform cross-section. For sections B and C for the plane side horizontal vibration, the projections acted somewhat as beams, causing the whole beam to behave as a beam of nonuniform section weighted at various points as indicated in Fig. 9. As the beam action of the projections was reduced by the addition of grooves as shown in Figs. 7 and 8, Eq. 31 held with increasing exactness. For the plane surface horizontal vibration of section D, the horizontal grooves were quite effective, probably because the transmission of shearing stress along the depth of the projections of the beam was prevented. These grooves would not be expected to be very effective in reducing the beam action of the projections with the plane surface placed vertically.

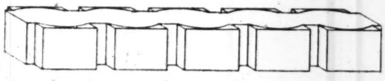


FIG. 9.—Beam of Variable Section with Distributed Weights.

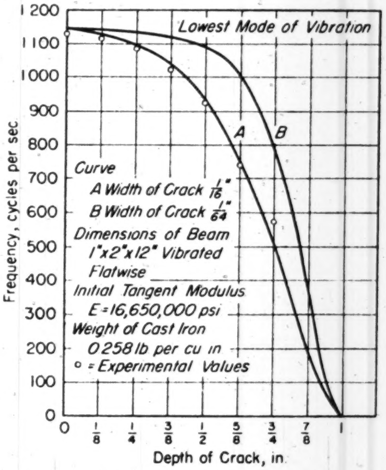


FIG. 10.—The Natural Frequency of a Free-Free Cast Iron Beam with One Crack at the Center.

TABLE II.—A COMPARISON OF CALCULATED MODULUS OF ELASTICITY OF MANY SECTIONED BEAMS WITH THE TRUE VALUE

	Modulus of Elasticity, psi. × 10^{-6}			
	Section A	Section B	Section C	Section D
Plane surface horizontal	15.75	20.05	16.40	15.90
Plane surface vertical	...	22.00	19.45	19.15

This indicates that in a beam of suddenly changing sections the corners are not very useful in carrying a load, but act only as weights. It also indicates that for a beam with several cracks, or changes in section, the calculation of the natural frequency would be extremely difficult unless the stress distribution at the cracks or corners were known.

CONCLUSIONS

On the basis of these analyses, the following conclusions are suggested:

1. The effect of a crack on the natural frequency of a beam is negligible if the crack is very narrow. Hence, an accurate modulus of elasticity can be determined for such a beam.

2. If the crack is filled with dirt or crystallized material, or is narrow enough so that interference occurs, the effect on the natural frequency is the same as that of a crack of lesser depth.

3. For the deterioration of concrete beams of the type characterized by a few narrow cracks, the loss in modulus of rupture should be far greater than the loss in modulus of elasticity determined by vibrations until the cracks become quite deep (greater than one half the depth of the beam). The correlation between loss in modulus of rupture and loss in modulus of elasticity should be expected to be poorer for neat cement and mortar beams and better for concrete beams, since the effect of the aggregate would be to increase the radius of curvature at the end of the crack, and hence reduce stress concentration.

4. For beams of many repeating sections, where each section behaves as a beam, the natural frequency is the same as that for a beam of constant cross-section whose stiffness and density are the average values for the many-section beam. This would suggest that for deterioration of concrete beams characterized by a very great number of small cracks the loss in modulus of rupture and in modulus of elasticity should be of the same order.

5. Since the modulus of elasticity of concrete varies with its strength (11) a good correlation between loss in modulus of elasticity and loss in modulus of rupture should be obtained for uncracked beams whose deterioration is characterized by weakening of the cement paste only.

6. A loss in modulus of elasticity as determined by vibrations always indicates a deterioration, but the type and extent of this deterioration are not certain.

REFERENCES

(1) T. C. Powers, "Measuring Young's Modulus of Elasticity by Means of Sonic Vibrations," *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part II, p. 460 (1938).

(2) L. Obert, "Sonic Method of Determining the Modulus of Elasticity of Building Materials Under Pressure," *Proceedings*, Am. Soc. Testing Mats., Vol. 39, p. 987 (1939).

(3) Floyd B. Hornibrook, "Application of Sonic Method to Freezing and Thawing Studies of Concrete," ASTM BULLETIN, No. 101, December, 1939, p. 5.

(4) W. T. Thomson, "Measuring Changes in Physical Properties of Concrete by the Dynamic Method," *Proceedings*, Am. Soc. Testing Mats., Vol. 40, p. 1113 (1940).

(5) T. F. Willis and M. E. DeReus, Discussion on Measuring Physical Properties of Concrete, *Proceedings*, Am. Soc. Testing Mats. Vol. 40, p. 1123 (1940).

(6) L. Obert and W. I. Duvall, "Discussion of Dynamic Methods of Testing Concrete with Suggestions for Standardization," *Proceedings*, Am. Soc. Testing Mats., Vol. 41, p. 1053 (1941).

(7) S. P. Timoshenko, "*Vibration Problems in Engineering*," Second Edition, D. Van Nostrand Co., New York, N. Y. (1937).

(8) S. P. Timoshenko and G. H. MacCullough, "Elements of Strength of Materials."

(9) E. Goens, "Uber die Bestimmung des Elastizitätmoduls von Staben mit Hilfe von Biegungeschwingungen," *Annalen der Physik*, 5th ser., Vol. 11, p. 649 (1931).

(10) J. P. Den Hartog, "*Mechanical Vibrations*," Second Edition, McGraw-Hill Book Co., Inc., New York, N. Y. (1940).

(11) P. M. Noble, "The Effect of Aggregate and Other Variables on the Elastic Properties of Concrete," Kansas State College Bulletin No. 29, p. 27, February 1, 1932.

MEASUREMENT OF FADING RESISTANCE OF CAMOUFLAGE TYPE FINISHES BY ACCELERATED WEATHERING

By J. W. Iliff[1] and L. B. Darrall[1]

One of the important characteristics of protective coatings is their ability to stand up under the conditions to which they will be subjected in practice. In particular, the most important single characteristic of a camouflage coating is its ability to retain its original color for a practical period of time under its conditions of use.

In the preparation of specifications for camouflage coatings, the Government agencies have included a color retention requirement in 60 odd different items. Furthermore, it has been necessary to use the accelerated weathering machine in specifying this color retention requirement, as no purchaser can wait for normal exposure to outdoor atmospheric conditions to determine the color retention characteristics of the product supplied by the paint manufacturer. Therefore, these different specifications include an accelerated weathering requirement and many of them also include an outdoor exposure requirement. The latter, however, has not been used in practice on account of the time factor mentioned.

As the user of camouflage finishes is primarily interested in its resistance to fading upon actual outdoor exposure and as the method of test which has been used is that of accelerated weathering, it seems worth while to review the accuracy of the accelerated weathering method in comparison with direct outdoor exposure. The work reported in the present paper constitutes such a check.

As a means of furnishing this check, comparisons were made using a camouflage paint covered by Army Engineer Specification T-1215 A and B with its fading resistance requirements as included in T-1213-B.

T-1215 type of paints are linseed oil finishes suitably pigmented and are supplied in nine colors as well as white and black. These nine colors were included in the study which is the subject of this paper.

Under T-1213-B the accelerated weathering requirement permits a certain degree of allowable color change after 300 hr. of exposure in the normal cycle of the National Carbon arc machine. It also specifies the same extent of allowable color change for 6 months exterior exposure. The color change permitted is descriptive only. The 300-hr. accelerated cycle was used in the present study. Six months of 45 deg. south in southern Florida exposure was used for the exterior location. It is recognized that the choice of Florida as the exterior exposure location may be subject to criticism because it differs considerably from more northerly places both as to speed and type of failure. It was chosen, however, for two reasons: first, the results are less affected by the time of year that the exposure is made, and second, previous work by Subcommittee VII on Accelerated Tests for Protective Coatings of A.S.T.M. Committee D-1 on Paint, Varnish, Lacquer, and Related Products has established it as yielding results closer to accelerated weathering than more northerly locations; hence, if correlation could not be established between the Florida exposure and accelerated weathering, there was little hope of obtaining correlation with more northern exposures.

---

[1] Laboratory, E. I. du Pont de Nemours and Co. Inc., Philadelphia, Pa.

The most important color change which is likely to occur on weathering exposure is that of fading or a lightening of the color. This may also be expressed as increased brightness. It is true that changes in hue are also important but this paper will be confined to fading changes only. Parker and Scofield[2] state that a change in brightness gives an adequate approximation of the color change, particularly when dealing with durable pigmentations.

Visual examination and personal rating of test exposures are customary when grading results. Such a method may have a serious error introduced by the individual judgment of the observer; consequently, a reduction to a quantitative method of measurement by suitable optical apparatus is much to be desired. One method of making such a measurement, which is receiving active consideration, is a reflectometer equipped with a suitable filter. Such apparatus actually measures the brightness of the paint film. With this instrument an increase in brightness implies and actually does give a reasonably accurate indication of fading or lightening of the color.

Through the courtesy of E. F. Hickson of the National Bureau of Standards, the results presented in the present paper were obtained with this method of examination.

The data presented are thus a direct comparison between the normal accelerated weathering cycle of the National Carbon arc machine and 6 months' 45 deg. exposure in Florida expressed in terms of fading as measured by a reflectometer equipped with a suitable filter.

The camouflage paints used in this test all met the essential requirements of T-1215-A or B, except for actual fading resistance. The composition of each of the paints in the nine different colors tested was varied in order to give different degrees of fading resistance within each color and, in the case of the more important colors, several different variations were made.

The results of the exposure of these paints to outdoor weathering and to the accelerated cycle are summarized in Figs. 1 to 4. Here a direct comparison of change in brightness units is made between accelerated weathering and outdoor exposure. It will be noted that the correlation is not a close one. Figures 5 and 6 bring this out more clearly in which is shown the variations of the accelerated weathering unit from the outdoor exposure taken as standard.

A change in the length of exposure to either outdoor exposure or the accelerated cycle would not have improved this result as the cycle was too fast for some paints and too slow for others. In Figs. 5 and 6 the accelerated cycle was too slow for all paints below the zero line, and too fast for those above.

A point of primary consideration, however, is the extent to which the error introduced by the accelerated weathering machine is likely to affect the acceptance or rejection of a manufacturer's product which may or may not be satisfactory as judged by actual outdoor exposure.

Some conversation which we have had with representatives of the Engineer Board indicates that a permissible increase in brightness might be limited to about $2\frac{1}{2}$ points on the scale shown.

---

[2] Official Digest, Federation of Paint and Varnish Production Clubs, May, 1944, p. 220.

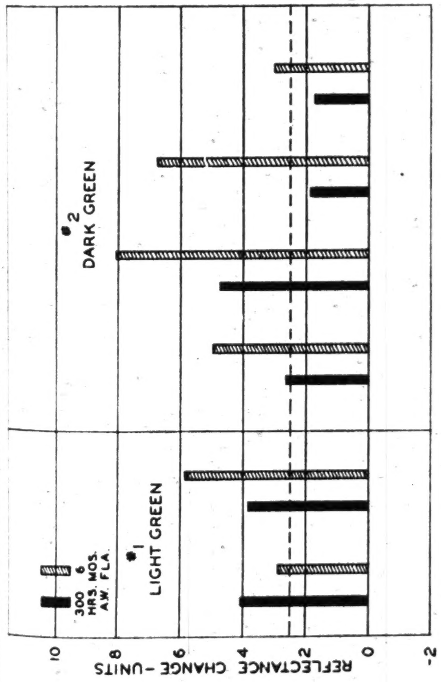


FIG. 1.

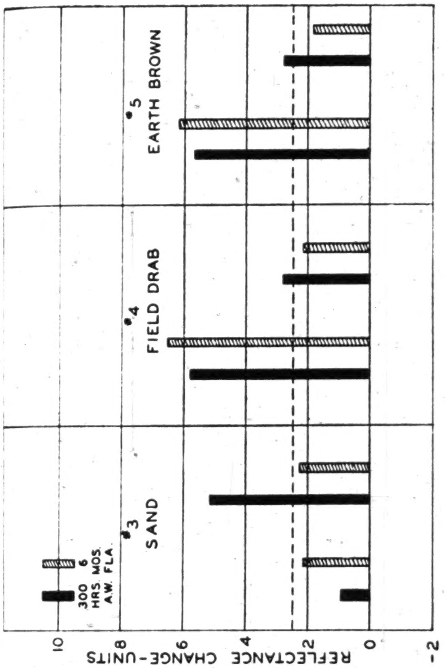


FIG. 2.

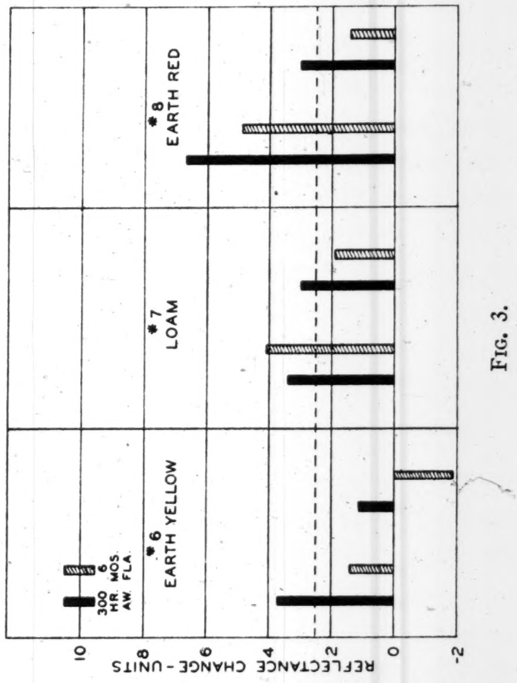


FIG. 3.

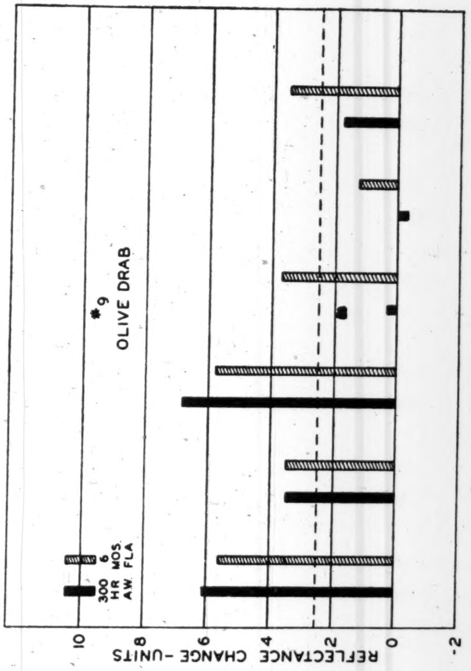


FIG. 4.

If we arbitrarily judge the results shown in the figures by this suggested requirement, we obtain the following:

Fourteen of the 34 paints included in the series would have been properly accepted or rejected by the accelerated weathering machine. In this group of 14, 3 were passed by the accelerated weathering machine and also passed by actual performance; 11 were rejected by the accelerated weathering machine and also rejected by actual outdoor exposure.

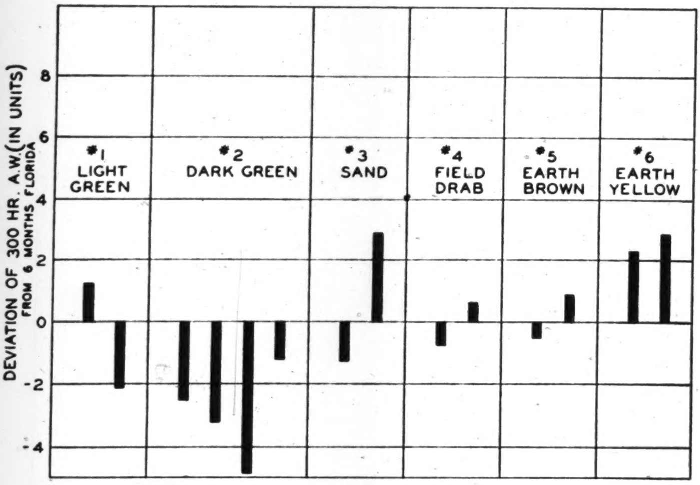


FIG. 5.

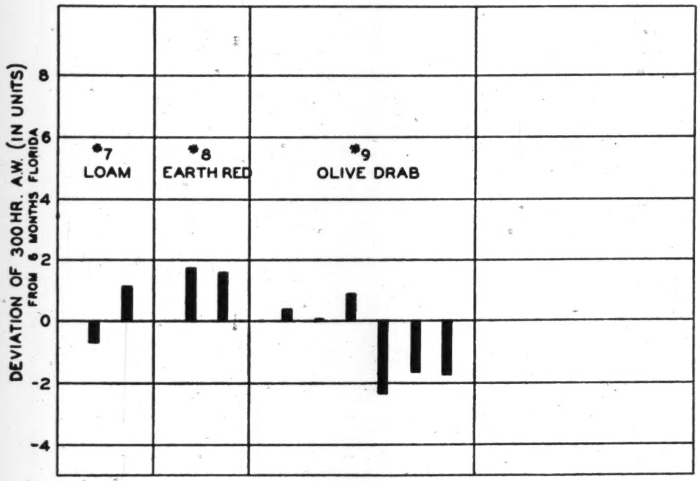


FIG. 6.

On the other hand, this accelerated weathering yardstick would have incorrectly rejected or accepted 10 of the 34 paints. Of these 10 paints, outdoor performance showed that 6 yielded satisfactory results, although the accelerated weathering machine would have rejected them. Similarly, the accelerated weathering machine passed 4 paints which outdoor exposure results show should have been rejected.

I wish to make one additional point clear and that is why we have confined our remarks to the National Carbon machine at its normal cycle, which is the one specified in T-1213-B. Comparisons have also been made, using other accelerated weathering machines and other cycles; some of which have previously been reported to Subcommittee VII. Of the cycles chosen, the one used in this paper is at least as accurate as any.

CONCLUSIONS

1. While accelerated weathering appears to be a necessary part of the specification of products subjected to outdoor exposure, its accuracy as indicated by the study of T-1215 type finishes leaves much to be desired. Moreover, its use might work an unjustified hardship on the paint manufacturer on one hand and, on the other, it might also result in the acceptance of unsatisfactory material by the purchaser.

2. It appears desirable to supplement accelerated weathering specifications in every instance by corresponding outdoor requirements. Provision should be made that the results of outdoor exposure supersede the accelerated weathering results as soon as they become available.

THE INTERPRETATION OF VISUAL RUSTING STANDARDS

By W. F. Singleton[1]

The A.S.T.M. photographic rusting standards for painted steel[2] set up by Committee D-1 on Paint, Varnish, Lacquer, and Related Products were designed "for comparative purposes," primarily in rating small panels. The type 1 standards, in fact, are reproductions in approximately half size of the surface of test panels with a weathered aluminum finish. The pattern of rusting is more or less circular small spots distributed at random. The gradation in severity of the rating depends on the number of spots and the increasing proportion of the total area which is covered with rust.

The type 2 standards are close-ups taken from actual structures. They represent rusting accompanied by blistering. This type of failure occurs when paint is applied over millscale after the scale has begun to rust. It is frequently encountered in the field, but it can be reproduced in panel tests only by unusual methods of exposure.

The A.S.T.M. standards have been used in our organization for routine grading of test fence exposures since they were first published. Experience with them has been very satisfactory. Ratings made by an inspector in Florida are generally in good agreement with ratings made independently on the same panels when they are returned to the laboratory in Pennsylvania. Before the rusting standards were adopted, a qualitative rating scheme was in effect, using the terms "slight," "considerable," or "bad" rusting. Such a scheme required personal training of the inspector in order to insure some degree of reproducibility, but its worst feature was the connotation of the qualitative terms. Actually, when a panel had reached the stage of "slight" rusting, it was in such advanced failure that an engineer would consider it ready for repainting.

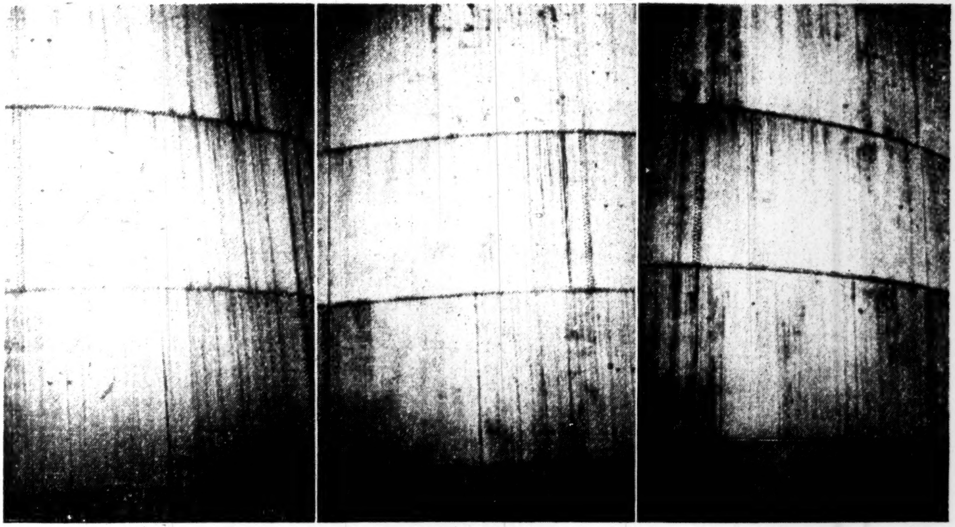
To the larger body of technical men who are paint users rather than paint makers, panel tests are only incidental. These men are concerned with the cost and quality of protection which the paint will give on structures in service. The goal of panel testing should be not merely to compare different paint compositions, but to determine the life of the paint on the structure. The result should be a quantitative figure representing the life of the paint system in months or years to the stage where repainting is necessary. This means that different types of panel must be selected according to the general structural features and the preparation of the steel for painting. The formulator must study several other variables beside paint composition. The description of any paint system on steel must include at least three items:

1. The condition of the steel surface when it is painted: Steel may be covered with scale; it may be partly or completely rusted. It may have been cleaned crudely by hand wire-brush or thor-

---

[1] Philadelphia Lab., Finishes Div., E. I. du Pont de Nemours & Co., Inc., Philadelphia, Pa.

[2] Standard Method for Evaluating Degree of Resistance to Rusting Obtained with Paint on Iron or Steel Surfaces (D 610 - 43), 1943 Supplement to Book of A.S.T.M. Standards, Part II, p. 73.



(*a*) No failure. (*b*) Beginning of rusting. (*c*) Repaint stage.

FIG. 1.—Gradation of Rusting on Sandblasted Storage Tank.

oughly by pickling and phosphate treatment. It may be smooth, pitted, or mechanically roughened.

2. Paint composition.
3. Thickness of the paint film.

After the paint system is thus specified, it must be exposed under conditions approximating actual service. When these conditions have been fulfilled, two questions arise in rating the panels: First, selection of a point in the rusting scale which corresponds to the repaint stage, so that the results may be translated into economic values. Second, how to fit into the A.S.T.M. numerical rusting scale patterns of failure which differ widely in appearance from the published photographic standards.

Figure 1 shows three sections of a large structure—a fuel oil storage tank—in varying degrees of rusting. This illustrates the most uniform failure which can be expected in practice. The paint system consists of sandblasted steel, primed immediately, followed by two

FIG. 2.—Spot Rusting on Sandblasted Tank.

topcoats, with a total average film thickness of 4 mils. A different primer was applied to each section. The paint system had been exposed 6 yr. when the photographs were taken.

A close-up of a heavily rusted small area in Fig. 2 illustrates the type of failure. It is pinpoint rusting distributed at random, as would be expected on a uniformly roughened clean steel surface. The pattern of failure corresponds to the A.S.T.M. type 1 standards.

There is no rusting on section (a) of the tank. Failure is beginning on section (b). There is considerable erosion of the aluminum topcoat showing the dark primer underneath, but visible spots of rust are confined to the top ring. In good maintenance practice the section might be repainted at this stage because of the erosion of the topcoat, but rusting is not yet definite enough to constitute an end point.

General rusting has occurred on section (*c*). All maintenance engineers would agree that the section needs to be repainted. This might be taken as marking the end point in the life of the paint system.

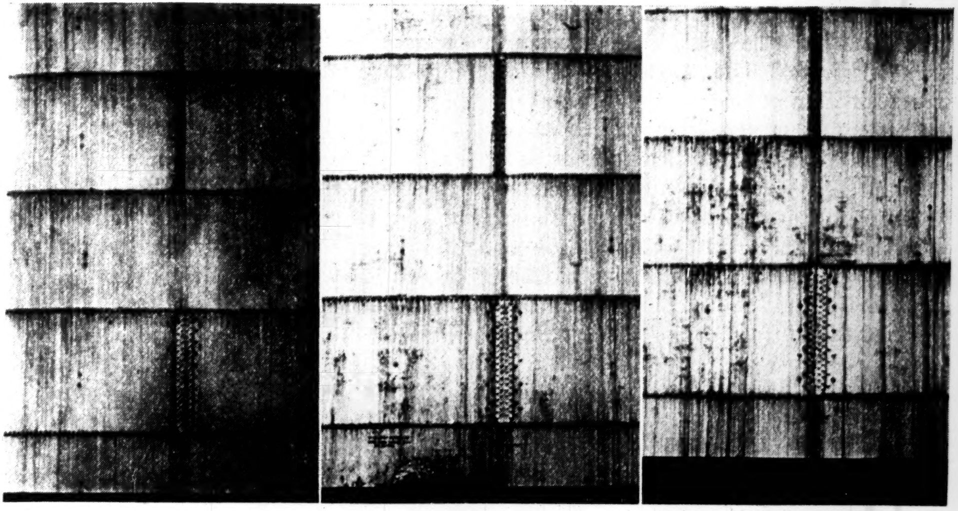
In attempting to apply the photographic standards to large areas such as sections of the storage tank, caution is needed because of the great difference in the linear scale of the field of view. The type 1 standards reproduce only a fraction of a square foot, while a section of the tank is hundreds of square feet. The severity of the rating depends not only on the total proportion of the area which is rusted, but also on the number of spots in which the rusted area is distributed; in other words, on the absolute diameter of the rust spots. The smaller the spots into which a given area of rust is divided, so long as they are easily visible, the more severe the rating. Since the same size spots look smaller on a large area, there is a tendency to rate large areas more severely than small ones. Or, to turn the proposition around, panels are usually judged optimistically because of their small scale. This has been one of the causes of the apparent lack of correlation between panel tests and actual service of paint systems in the past.

Section (*a*) rates No. 10 in the A.S.T.M. scale without question because there is no failure. In rating section (*b*), allowance must be made for the fact that erosion may be mistaken for rust in the photograph. This section is really better than No. 9 rusting.

It is in rating an area such as section (*c*) that serious difficulty is encountered. The rust is not distributed uniformly over the entire section. There are many small areas, such as Fig. 2, where rusting has advanced to No. 7 or even No. 6. There are other larger areas with little or no rusting. What is desired is an over-all rating for the section. One must also take into account the difference in linear scale; this can be done by visualizing a large surface having the same area as the section of the storage tank covered with small units rusted to the degree of the photographic standard. With these considerations in mind, the author believes that a reasonable rating for section (*c*) is No. 8, and that this may be taken as representing the repaint stage.

Figure 3 is a similar gradation of rusting on a storage tank which is failing in the pattern of the type 2 standards. The close-up of a badly rusted small area in Fig. 4 shows both unbroken blisters and a few blisters which have broken open revealing dark rust underneath.

The paint system consists of three coats at an average thickness of 5 mils on steel plate which was covered with millscale. The steel had become partly rusted during erection. It was prepared for painting by hand scraping and wire brush. The exposure was only 2 yr.



(*a*) No failure. (*b*) Repaint stage. (*c*) **Rusting worse than repaint stage.**

FIG. 3.—Gradation of Rusting on Wirebrushed Storage Tank.

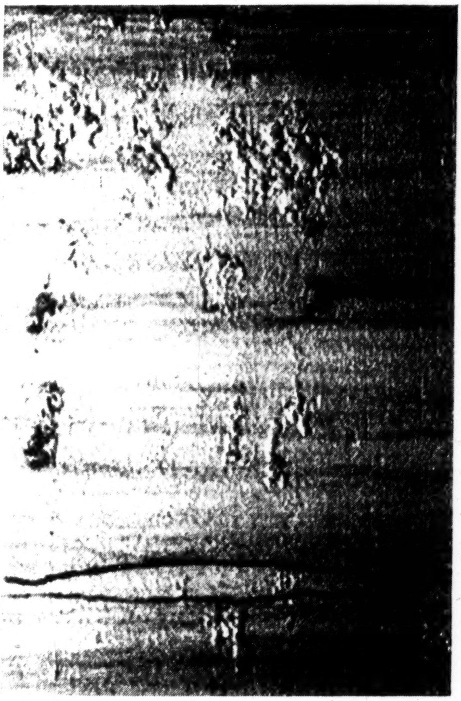


FIG. 4.—Blister Type Rusting on Wirebrushed Tank.

in the same locality as the fuel oil storage tank in Fig. 1.

Section (*a*) is rated No. 10 (A.S.T.M.) because there is no failure. Section (*b*) has already reached the repaint stage. In rating this section, as in the previous example, allowance must be made both for the occurrence of small patches showing all degrees of rust from No. 10 to No. 6, and for the difference in linear scale from the photographic standard. A rating of No. 8 again seems reasonable. Section (*c*) has progressed beyond the repaint stage, and may be assigned a rating of No. 7.

Several of the primers on sections of this tank were the same as on sections of the sandblasted tank. The short life of 2 yr. as contrasted with 6 yr. for a thinner paint film on the sandblasted surface illustrates the importance of specifying the surface condition of the steel when an estimate of the life of the paint system is to be made.

In contrast to the relatively flat surface of steel plate in a storage tank, the steel work in a bridge presents a repetition of rolled and cut edges, angles, joints, and lines of rivets. The preponderance of structural shapes over plates brings out the second problem in the interpretation of rusting standards. Rusting is not distributed at random, but tends to be concentrated at raised places and sharp edges where the paint coating is likely to be thin or where rusting was farther advanced before the steel was painted. Figure 5 illustrates flange rusting on a bridge. The rusting results from the difficulty of applying a normal thickness of paint to the rolled edge. Failure in this instance is not so far advanced as the repaint stage; the structure can be put into perfect shape merely by striping the edge.

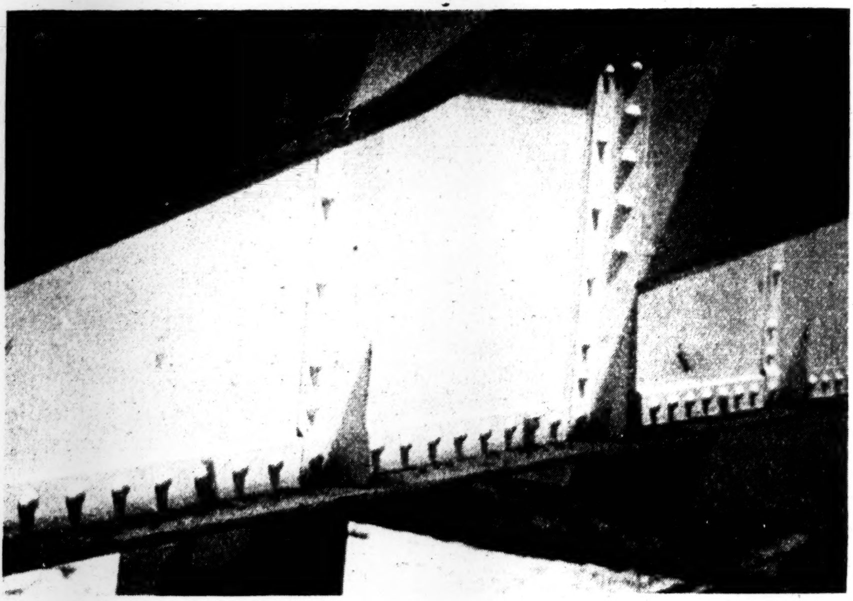


FIG. 5.—Flange Rusting on a Bridge.

The main features of failure on structural steel shapes can be reproduced on panels. One type of panel which has been found convenient and suitable is merely a length of heavy 4-in. steel channel. When flange rusting is the chief type of failure on such panels they cannot be rated directly by the A.S.T.M. photographic standards because the pattern of failure is quite different. It becomes necessary to develop a rating scale of flange rusting for the guidance of inspectors at the test fence. A photographic series set up in steps corresponding to the A.S.T.M. scale is shown in Fig. 6. The first step is rated No. 9. The next step was given a rating of No. 8. This was judged to be the point at which repainting would be required in practice and corresponds to the view developed in this paper that a rating of No. 8 on the A.S.T.M. scale approximates the repaint point. The standard set up for No. 7 rating is by necessity a touched-up photograph, because every panel examined to date shows some rusting on the web as well as on the flange when failure has progressed so far. The A.S.T.M. type 2 photographic standards can be used directly for the lower grades.

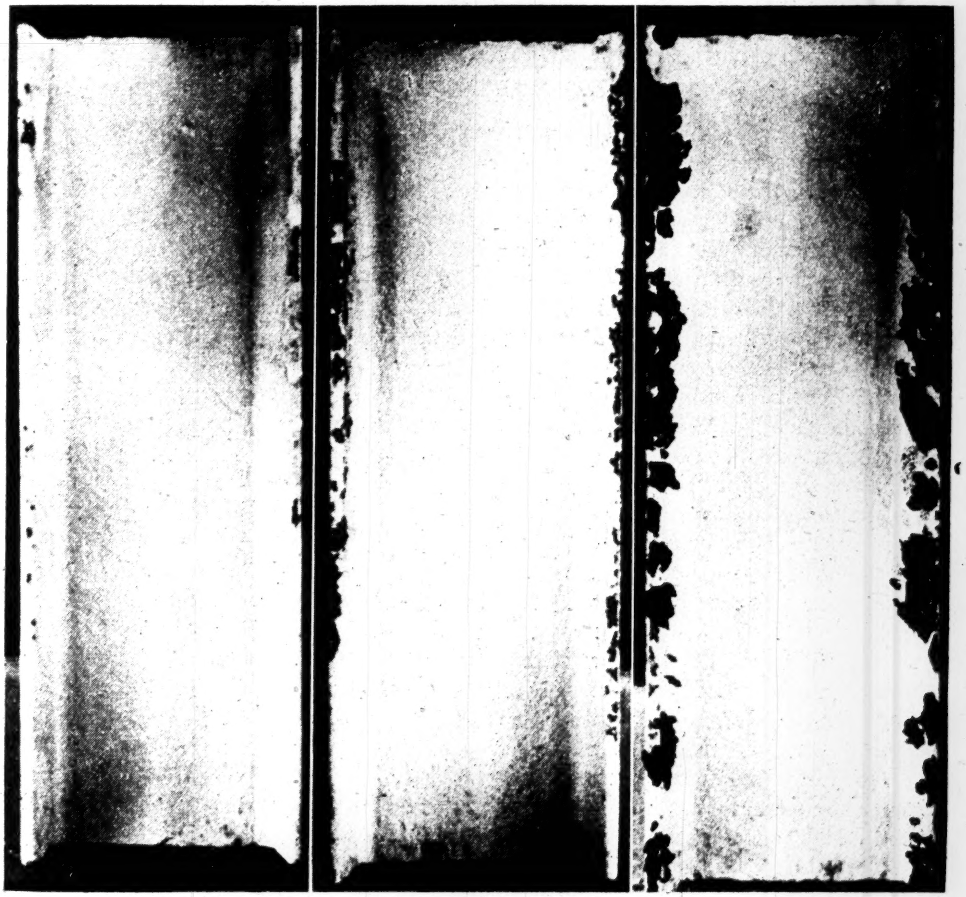

No. 9 No. 8 No. 7

FIG. 6.—Rating Scale for Flange Rusting.

Although the A.S.T.M. photographic standards are not directly applicable to all patterns of rusting on painted steel, they do provide a common numerical scale in which all observations can be recorded. The steps on that scale have practical meaning in terms of the life of the paint system. The definiteness with which results can be reported should increase the significance of research on coatings for steel.

FACTORS INFLUENCING THE BREAKING STRENGTH OF ARMY AND NAVY FABRICS

By Werner von Bergen,[1] John C. Hintermaier,[1] and Eric Ullman[1]

The U. S. Army and Navy set up rather rigid limits and specifications for the texture and other physical characteristics their military cloth should have. In these specifications a predominant place is taken by minimum limits for breaking strength.

For this presentation, analyzing the factors influencing the breaking strength, two fabrics were selected, the 18-oz. serge, olive drab, for the Army and the 16-oz. melton, blue, for the Navy. The reasons for the choice of serge and melton were threefold: first, because they are the two most common military fabrics; second, they represent both the worsted and woolen branches of the textile industry; and, third, the breaking strength specifications for both were revised downward after it was found that too few manufacturers were able to meet the higher requirements. The former serge specifications called for 120 lb. in warp and filling while the melton specifications called for 62 lb. in warp and 50 lb. in filling.

Analysis of Present Specifications

The U. S. Army and Navy specifications call for deliveries according to standard samples in so far as color, texture of the fabric, and general appearance are concerned and read in their main physical requirements as set forth in Tables IA and IB.

The serge specifications require that the cloth carry a theoretical load of 1.76 lb. per warp yarn in the 1 by 1 by 3-in. grab test before breaking. On the same basis the filling strength demand is 2.04 lb. per yarn. Since the appearance of the twill in the finished cloth restricts the manufacturer to using the same thread in both warp and filling, there is evidently an unbalance in thread strength demand. The filling is expected to be 17 per cent stronger than the warp.

As the warp direction is the one considered to carry the greatest strain in wearing, let us take 120 lb. (1.76 lb. per yarn) as the basis. Calculating (54 threads per in.) the theoretical filling requirement for balanced strength demand, the result is found to be 95 lb.

The melton specifications require a cloth with 58 lb. warp and 46 lb. filling strength. The calculation of the theoretical strength demand per yarn gives 0.97 lb. for warp and 0.84 lb. for filling. The logical relation between the coarser warp and finer filling found in the standard sample is preserved. The filling is expected to carry 13 per cent less load per thread than the warp and should, therefore, be finer.

The Philadelphia Quartermaster Depot has already made a study[2] of the serge as produced by 29 mills, a cross-section of practically the entire worsted manufacturing industry. Samples of 18-oz. serge from each mill were tested for strength, weight, ends, and picks. All the manufacturing processes used were tabulated for comparison. It is interesting to note the variety of results this industry survey reveals. As regards breaking strength, from the data in Fig. 24 of the report,[2] we find an average warp strength of 144 lb., range 130 to 156 lb., and an average filling strength of 115 lb., range 98 to 132 lb. The standard deviations are 5.90 and 7.25, respectively.

---

[1] Director of Research and Control Laboratories, Supervisor of Cloth Control, and Textile Technologist, respectively, Forstmann Woolen Co., Passaic, N. J.

[2] Report on Survey of Various Manufacturing Methods in Use by Worsted Industry for Production of Cloth, Serge, O.D., 18 Ounce.
Prepared under the Direction of the Commanding Officer, Philadelphia Quartermaster Depot. July 10, 1943.

TABLE IA.—CLOTH: SERGE, OLIVE DRAB, 18 OZ.

Wool: The wool for warp and filling shall be fleece and/or pulled wool not lower in grade than 64's United States standard.

Yarn: The wool shall be well combed, drawn, evenly spun on the worsted system and twisted into a two-ply yarn for both warp and filling. The yarn shall have sufficient twist to insure a character of cloth as shown by the sealed standard sample.

Weave: The weave shall be a four harness twill to the right, two up and two down.

Color: The color shall be olive drab produced by blending shades of olive with white wool and shall match that of the standard sample.

Thread Count, minimum per in.		Breaking Strength, lb., min., 1 by 1 by 3-in. grab method	
Warp	Filling	Warp	Filling
68	54	120	110

The above figures show, with their accompanying statistical inferences, that all manufacturers are not equally successful in meeting the specifications. It is apparent that the main difficulty was in meeting the filling breaking strength requirements.

The manufacturers who delivered pieces with the lowest warp breaking strength were still 10 lb. above specification while their filling strength was as much as 12 lb. below specification. This observation bears out the fact that a lack of balance exists in the specifications.

In order to meet cloth specifications it is essential for the manufacturer to be familiar with the extent of variations influencing the breaking strength which occurs in the production of his cloth. In addition to the raw material chosen, manufacturing processes, such as dyeing, spinning, weaving, and finishing, have a definite bearing on the breaking strength in the finished cloth. How great are these influences and what fluctuations occur? What are the main factors causing the strength variations in the yarns and how much are these differences responsible for strength variations in the cloth? To what extent is it possible to predict the finished strength—from the yarn strength or raw piece strength? Do weaving and finishing reduce or enlarge the variations?

TABLE IB.—CLOTH: MELTON, BLUE, 16 OZ.

Wool: The wool for warp and filling shall be fleece wool, of a grade not lower than 64's (U. S. Standard), and with staple of sufficient length to meet the hereinafter described requirements. The wool shall be free from the admixture of vegetable matter, reworked wools, waste, or any other adulterants.

Yarn: Shall be equal to that of the standard sample (which was carded, spun on woolen system, singles for both warp and filling).

Weave: Shall be a two up and one down, twill to the right.

Color: Shall be piece or stock dyed with suitable colors of required fastness properties so as to produce the shade of the standard sample.

Thread Count, min. per in.		Breaking Strength, lb., min., 1 by 1 by 3-in. grab method	
Warp	Filling	Warp	Filling
60	55	58	46

In this paper emphasis is placed upon

the variations experienced. It is the purpose of this study to present these as a step forward in the long trail toward complete knowledge of the inherent quality characteristics of cloth production. The data are not advanced as criteria to be reached but as examples of the variations within one mill.

Manufacturing and Testing Routines:

The data were accumulated over approximately two years of actual military production. Testing was carried out both under mill operating conditions and under laboratory controlled conditions. In general, the test procedures and methods used were standard A.S.T.M. procedures with a few exceptions developed on the basis of experience.

To show the points of control testing in the general manufacturing routines of the two cloths, the following flow sheet is given. The test procedure is found by reference to the key.

FLOW SHEET OF MANUFACTURE AND TESTING PROCEDURES

Worsted 18-oz. Serge		*Woolen* 16-oz. Melton	
Raw wool	1	Raw wool	1
Sorting		Sorting	
Scouring		Scouring	
Combing	1, 2, 3	Stock dyeing	
Top dyeing	3	Carding	1
Spinning	4, 5, 6	Spinning	4, 5, 6
Weaving		Weaving	
Grey goods	4, 7, 8, 9	Grey goods	4, 7, 8, 9
Fulling	10	Fulling	10
Washing	4	Washing	4, 12
Crabbing		Carbonizing	
Drying		Neutralizing	4
Specking	11	Decating	
Shearing		Drying	
Decating		Shearing	
Final examining		Pressing	
Finished cloth	4, 7, 8, 9, 13, 14, 15, 16	Final examining	
		Finished cloth	4, 7, 8, 9, 12, 13, 14, 15, 16

Key	*A.S.T.M. Standards*[a]
(1) Fiber fineness	D 419 - 37, D 472 - 41
(2) Fiber length	D 519 - 40
(3) Tensile strength (bundle)	
(4) Breaking strength (5) Yarn number (count) (6) Twist	D 39 - 39, D 403 - 38, D 404 - 38
(7) Ounce weight	D 39 - 39
(8) Piece length and weight	
(9) Picks per in.	D 39 - 39
(10) Fulling time	
(11) Specking time	
(12) Crocking	A.A.T.C.C. Standard method
(13) Width	D 39 - 39
(14) Ends per in.	D 39 - 39
(15) Weight and length loss	
(16) Color fastness to light	D 506 - 41

---

[a] 1942 Book of A.S.T.M. Standards, Part III.

PART I—STRENGTH VARIATIONS IN FINISHED PIECES

The data are presented starting with finished pieces; tracing the way back to the yarn and wool. In order to facilitate the presentation of both the strength levels and the variations at these levels, control charts and graphs have been used wherever possible. The points plotted represent the averages of groups of test results. From a normal uniform production, these points differ from their grand averages by amounts not greater than can be calculated from well-known probability formulas.

The probability that a point (group average) will fall outside control limits by chance alone is approximately three in one thousand. These control charts contain selected parts from our production records chosen to demonstrate the effects of various influences. They are not in proportion to the actual production but fairly represent variations which we experienced.

In collecting breaking strength data on finished cloth, the most important step is the selection of proper samples. The sampling procedure used insures randomness, economy, and representativeness. The method is as follows:

(*a*) From the first 25 pieces of new production every piece (100 per cent) is tested. (See test procedure)

(*b*) From then on, every fifth piece (20 per cent) is tested until data on 25 more have been accumulated.

(*c*) From then on, every tenth piece (10 per cent) is tested until data on 25 more have been accumulated.

(*d*) From then on, every twentieth piece is tested (5 per cent) until data on 25 more have been accumulated.

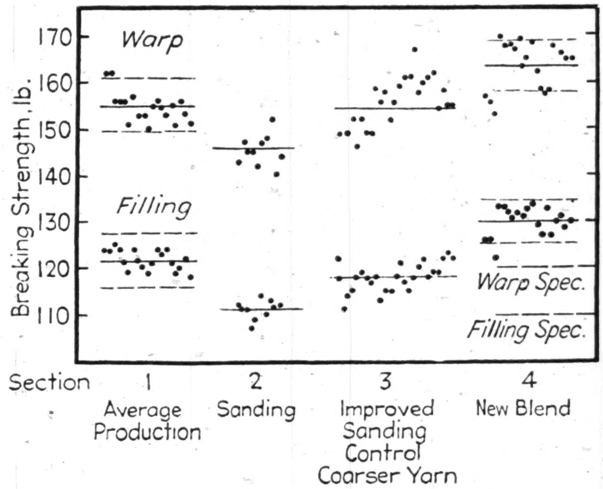


FIG. 1.—Control Chart for Serge Pieces.

(*e*) From then on, sampling is one piece per day (0.3 to 2 per cent)

(*f*) If at any time during the above schedule major changes in processing or raw material occur, the schedule reverts to step (*a*) or (*b*) at the discretion of the control engineer. Upon restarting an interrupted flow of production on one kind of cloth, steps (*b*) or (*c*) may be eliminated, provided the data of step (*a*) equal previous production levels.

The testing was done under mill atmospheric conditions in the finished cloth examining department. The strength data as well as piece length, weight, and width were accumulated on specially printed forms containing 20 pieces. As each group of ten pieces was completed, its statistics were calculated and entered on a control chart. For piece goods each point represents the group average of 10 pieces; for yarns 5 bobbins for strength and count. In order to calculate control limits, ranges for the groups are averaged. The average range is multiplied by the proper A_2 factor for sample size.[3] The resulting figure added to and subtracted from the average of all the strengths gives the upper and lower limits, respectively. One chart was kept for each kind of cloth produced.

SERGE

The layout used for making the Army serge was as follows:

Stock—Domestic wool 64's
Top fineness 21.2 microns
Top length 2.2 in.
Blend { 73 per cent dyed top—metachrome process
27 per cent white recombed top
Warp and filling yarn single 1/26.5m.
Z40
Worsted system equivalent 1/23.5
Grex equivalent..........377 grex
Warp and filling yarn plied 2/26.5 m.
Z40 **S**48
Worsted system equivalent 2/23.5
Grex equivalent..........2/377 grex
Warp 3900 ends (58 per in. on loom)
Width on loom 67½ in.
Picks on loom 51 per in.

The finishing routine comprised raw fulling, washing, crabbing, drying, specking, shearing, decating, and final examining.

---

[3] A.S.T.M. Manual on Presentation of Data, Reprinting April, 1943.

The control chart, Fig. 1, of breaking strength shows considerable variations among groups of pieces. The chart is divided into four sections. Each section represents a major change in manufacturing. The first section is self-explanatory. At that time mill production allowed recombing the white top. As production volume increased, it was found necessary to discontinue the recombing. This resulted in a considerable increase of neps in the cloth. Sanding, a purely mechanical operation, was introduced (section 2) in the finishing routine to reduce the neps to a satisfactory level. The nep reduction was successful but the operation had a damaging effect on the yarns thereby reducing the breaking strength, especially in the filling direction. In order to return the production level to a satisfactory distance above the 110-lb. filling strength specification, the 2/26.5 m. yarn formerly used was replaced by 2/26 m. and stricter control of the sanding operation was instituted. The result of this change is shown in section 3. Since points still occurred very close to the minimum strength, a further change was made. Section 4 represents pieces made from a blend of 50 per cent Australian wool and 50 per cent domestic wool.

Variation Within Pieces:

It must be realized that within the groups on the chart additional variations exist. The same thought may then be extended to individual pieces. In order to demonstrate the variations existing within a piece, successive specimens were taken across one piece from selvage to selvage. The specimens were spaced so that different groups of warp and filling yarns were tested. The specimens were cut in duplicate so that one set could be tested under mill conditions and the other set under standard conditions of 65 per cent relative humidity and 70 F. In addition, (for the filling alone), the same group of yarns was repeatedly tested across the piece. The data were analyzed by application of tests for significant differences (**Z** test)[4] in variability. See Table II.

TABLE II.—STRENGTH VARIATIONS WITHIN ONE SERGE PIECE.

	Mill Conditions		Standard Conditions		
	Warp	Filling	Warp	Filling	
	1	*2*	*3*	*4*	*5*
Number of tests	11 (dif.)	11 (dif.)	11 (dif.)	11 (dif.)	6-(same)
Average strength, lb.	158.0	128.1	195.1	127.2	128.5
Standard deviation, lb.	4.70	4.50	5.83	4.80	2.65
Range within piece, lb.					
Calculated	28.2	27.0	35.0	28.8	15.9
Actual	14.0	16.0	20.0	12.0	4.0

TESTS FOR SIGNIFICANT DIFFERENCE OF STANDARD DEVIATIONS

	Z Calculated	0.95 limit[a]
Between warp, col. 1 and col. 3	0.2152	0.5196
Between warp and filling, col. 3 and col. 4	0.0201	0.5196
Between filling (dif.), col. 2 and col. 4	0.0642	0.5196
Between different filling and same filling, col. 4 and col. 5	0.5941	0.6976[b]

[a] *Z* calculated must exceed the 0.95 limit, n_1, n_2 = 11, for significant difference to be proven.
[b] Limit for n_1 = 11, n_2 = 6.

---

[4] Applied General Statistics, F. E. Croxton and D.J. Cowden, Prentice Hall, 1941.

TABLE III.—PIECE STRENGTH STATISTICS, SERGE—MILL TESTING CONDITIONS.

	Warp				Filling		
	Sample Size	Average, lb.	Standard Deviation, lb.	Coefficient of Variation, per cent	Average, lb.	Standard Deviation, lb.	Coefficient of Variation, per cent
1. Average production	200	153.8	6.61	4.30	121.5	6.38	5.23
2. Sanded........	100	145.7	5.79	3.97	111.1	5.04	4.54
3. Improved sanding coarser yarn	240	156.2	6.66	4.26	119.5	7.02	5.87
4. New blend....	190	163.6	7.30	4.46	130.0	5.75	4.42

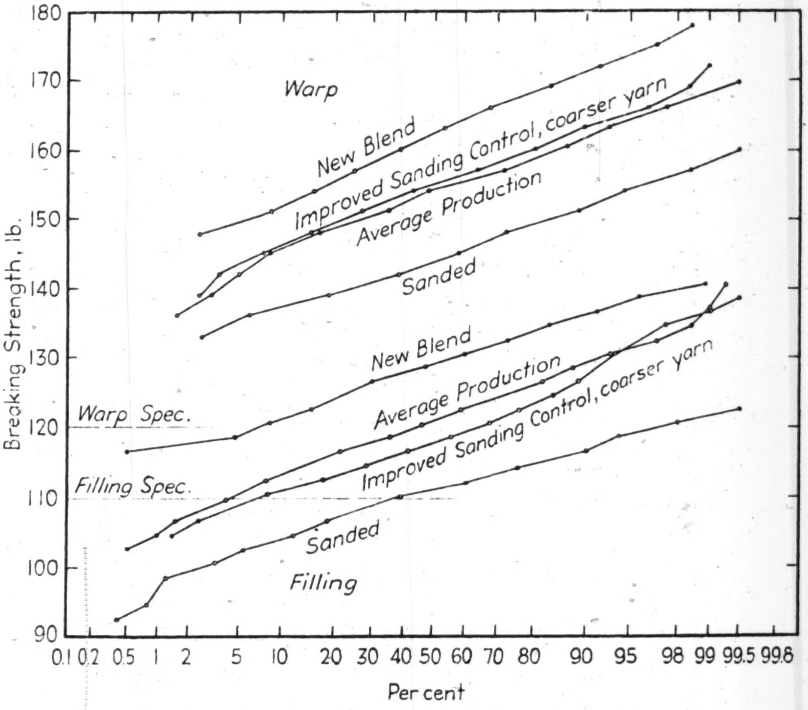


FIG. 2.—Cumulative Curve, Serge Piece Strength.

The above figures indicate that variations as high as 35 lb. may exist within a piece. This is an extreme and is seldom found in practice. The usual range of test values is between 10 and 20 lb. in both warp and filling. The apparent differences in standard deviations are functions of sampling fluctuations and sample size. Testing under standard conditions apparently has no influence on individual piece variability as shown by the Z tests. None of the differences could be proved significant.

Variation Among Pieces:

The variations among pieces are calculated from the pieces used in the control charts. Within each group of ten shown on the control chart, Fig. 1, there are many variations from piece to piece. The extent of these variations is indicated by the analysis of figures given in Table III. For average production, the 6 σ range (3 standard deviations above average plus 3 standard deviations below average equals total range) of strength results among pieces shows that as high as 40 lb. difference may be expected between the weakest and strongest pieces coming from normal production. This strength range holds approximately for both warp and filling.

The question immediately arises, how are the piece strengths distributed within this range? For demonstrating this distribution, the data of the piece strengths were tabulated in cumulative form on arithmetical probability paper. Figure 2 is the graphic representation of the extent of variations which lie behind the control charts.

A normal distribution yields a straight line when plotted on arithmetic probability paper. Since the points represent the actual test observations it is clear that the agreement between the test data and the theoretical straight line is only approximate.

The application of normal curve formulas to such data yields only estimates of the actual extremes. As the test data depart further from normality, greater errors in estimation are made. These errors are of a directional character. They yield calculations estimating more low strength pieces than actually exist. The error will give a somewhat more gloomy picture of the state of production. For example, 41 per cent of the sanded serge pieces were calculated as failing to meet specifications, whereas actually 38 per cent failed during the beginning of sanding operation. The calculation is given below:

Serge, sanded—Filling average 111.1 lb., standard deviation 5.04 lb.

What per cent of production may be expected below specification limit of 110 lb.?

$$\frac{\text{Difference Specification from Average}}{\text{Standard Deviation}} =$$

$$\frac{111.1 - 110}{5.04} = 0.218$$

In order to translate deviation into percentage of pieces within certain strength limits we must use a table of areas under the normal curve. The value opposite 0.218 in such a table is 0.0864 or 8.64 per cent of pieces have their strength between the average and the specification. Since the average divides the population in half, 50 per cent lie above average making a total of 58.64 per cent above specification and 41.36 per cent below specification.

The cumulative type curve of Fig. 2 is given for estimation of the proportion lying below any strength level. It is determined by reading vertically downward from the intersection of the horizontal strength line and the curve to the percentage scale. Subtraction from 100 per cent then yields the fraction passing the specifications:

1. Average production, not sanded, 100 − 4 = 96 per cent above specification
2. Average production, sanded, 100 − 38 = 62 per cent above specification
3. Improved sanding, coarser yarn, 100 − 7 = 93 per cent above specification
4. New blend.......... more than 99.5 per cent above specification

When the above examples of variations within and among pieces are combined, we then have variations among groups of pieces. The analysis of groups of pieces is best shown by control chart, Fig. 1. The chart shows four definite strength levels for both warp and filling: namely,

Section	Number of Points	Warp		Filling	
		Breaking Strength, lb.	Range for 10 Piece Points	Breaking Strength, lb.	Range for 10 Piece Points
1......	20	153.8	±5.5	121.5	±5.8
2......	10	145.7	...	111.1	...
3......	24	156.2	...	119.5	...
4......	19	163.6	±5.6	130.0	±4.5

The first section represents average production. The effect of the sanding operation is demonstrated by the low level of the second section of Fig. 1. This is definitely out of control[5] with respect to section 1 and an entirely new level was established. It is immediately apparent that a certain proportion of pieces fails to meet the 110 lb. specification for filling strength. Sanding lowered the filling strength level approximately 9 per cent, bringing a large proportion (calculated to be 41 per cent) of the pieces below minimum specifications. The warp strength level was lowered 5 per cent.

---

[5] Control limits are valueless for these figures because of trend.

The combined effect of better control of the sanding operation and coarser yarn size is shown in the third section. This shows the improvement effected. While the average warp strength is back to its previous level, it does not exhibit control.[5] A trend is shown toward a higher level. A parallel trend toward a higher level is also shown in the filling.[5] The filling strength level is not as high as the original standard but the proportion of pieces falling below specifications is now very small. The new levels are only 0.3 per cent below the original in warp and 3 per cent in filling. There are still 7 per cent of pieces below specification level.

The new levels of the fourth section are the result of a new blend of 50 per cent Australian wool with 50 per cent domestic wool. The resulting top had an average length of 3.05 in. and the fineness averaged 22 microns. The final level was 6 per cent superior to the original. The probability of pieces being below specification was less than 3 chances in 1000. No pieces, however, were found below specification.

NAVY BLUE MELTON

The second cloth—16 oz. navy blue melton—was selected to represent the fluctuations encountered in the manufacture of tightly felted cloth from wool spun yarn. The specifications have already been given. (Table IB). In order to produce such a cloth, we started with the following layout:

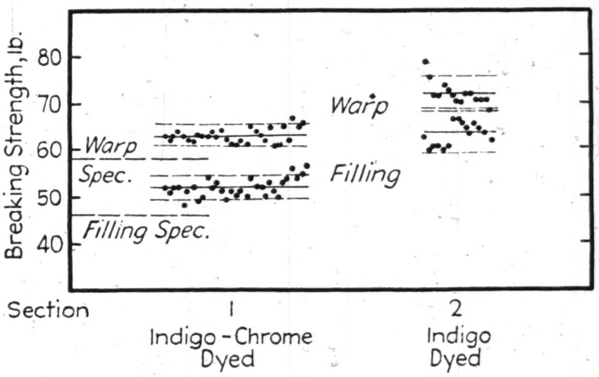


FIG. 3.—Control Chart for Melton Pieces.

Wool:	64's cape wool length 2.0 in. fineness 20.5 microns
Stock dyeing:	Indigo bottom—chrome topped[a]
Yarn:	Warp—14 m. (4.33 Runs, 715 grex) Twist S52 (Mule Spun) Filling—16 m. (4.96 Runs, 625 grex) Twist Z50 (Mule Spun)
Weaving:	Warp 3390 ends (40 per in. on loom) Width on loom 85½ in. Picks on loom 45

---

[a] Though the Navy originally specified a chrome bottom and indigo top, the above procedure involved dyeing the indigo first and topping it with chrome colors. This eventually led to the continuous stock dyeing of indigo alone, eliminating the use of chrome colors entirely.

The finishing routine was fulling, washing, carbonizing, neutralizing, wet decating, drying, shearing, pressing, and final examining.

The melton control chart, Fig. 3, illustrates variations among the piece groups. These variations, similar to those observed in the serge, are the result of inherent differences from piece to piece and within pieces themselves.

Variation Within a Piece:

The standard deviations of the breaking strength observations from successive specimens taken across a piece from selvage to selvage are given in the Table IV.

TABLE IV.—VARIATIONS WITHIN ONE MELTON PIECE.

	Mill Conditions		Standard Conditions		
	Warp	Filling	Warp	Filling	
Number of tests	11 (dif.)	13 (dif.)	11 (dif.)	11 (dif.)	6 (same)
Average strength, lb.	59.1	50.8	60.72	50.3	50.7
Standard deviation, lb.	1.73	2.02	1.92	1.95	3.02
Range within piece, lb.					
Calculated	10.4	12.1	11.5	11.7	18.1
Actual	5.0	6.0	7.0	6.0	9.0

TABLE V.—PIECE STRENGTH STATISTICS, MELTON—MILL TESTING CONDITIONS.

	Sample Size	Warp			Filling		
		Average, lb.	Standard Deviation, lb.	Coefficient of Variation, per cent	Average, lb.	Standard Deviation, lb.	Coefficient of Variation, per cent
Indigo chrome	310	63.1	2.4	3.8	52.0	3.72	7.15
Indigo	150	72.4	4.37	6.04	63.2	5.14	8.13

From the calculated range, that is, six times the standard deviation, variations as high as 18 lb. within one piece may be found. In actual testing, this extreme range was seldom reached. The usual range within a piece was between 4 and 8 lb.

The closeness of the standard deviations between mill testing and standard conditions is further proof that differences in test conditions do not affect variability.

The **Z** test on standard deviation for comparison of tests between same filling and different filling yarns gives a value of 0.4377. The limiting value for Z is 0.6976. Therefore, the variability of testing different groups of filling yarns is shown to be not significantly different from that of the same group of yarns.

Variations Among Pieces:

It must be realized that not every piece will show the same variations within its borders. These differences then form the second set of variations among pieces.

The figures given in Table V are the statistics calculated from the pieces selected for the control chart Fig. 3. From the 6σ range strength variations of approximately 16 lb. between weakest and strongest indigo chrome pieces may be expected. The indigo pieces have a higher range—approximately 28 lb. between the extremes.

The above ranges are calculated ranges. In actual practice only a few pieces were found to reach such extremes. The usual range among pieces was 10 lb. for indigo chrome and 12 lb. for indigo.

In order to answer questions as to how much of production deviates from acceptable (specification) level, the proportion of pieces at the various levels must be known. The cumulative curves of Fig. 4 enable the determination of how many pieces do and do not meet the strength specifications. By reference to the warp curve for indigo chrome pieces, 8 per cent fail to reach 58 lb. The curve of filling strength of indigo chrome pieces indicates 5 per cent fail to reach 46 lb. The warp and filling curves for indigo pieces are so much above specifications that the probability of any failing is 3 in 1000 or less.

The combining of pieces into groups as is done on the control charts introduces again the concept of variations among groups of pieces. There are two major influences to demonstrate in the melton piece control chart, Fig. 3. The levels of these sections and their control limits are tabulated below:

Section	Number of Points	Warp		Filling	
		Breaking Strength, lb.	Range for 10 Piece Points	Breaking Strength, lb.	Range for 10 Piece Points
1	31	63.1	±2.2	52.0	±2.4
2	15	72.4	±3.3	63.2	±4.5

The first section is that of the indigo chrome dyed wool. Since the lower limits of this section are close to the specification, individual pieces fall below the minimums. The small percentage of pieces failing to meet specifications was completely eliminated in the second section. The pieces in this section are stock dyed with indigo only, no chrome colors were used.

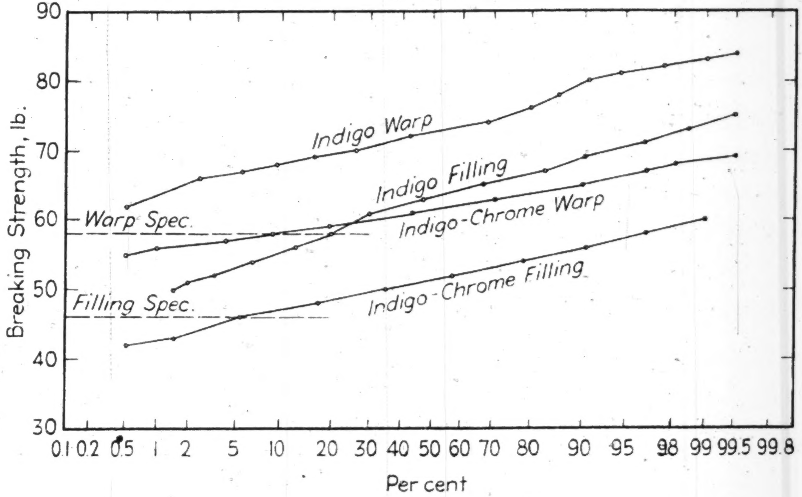


FIG. 4.—Cumulative Curve, Melton Piece Strength.

The radical change in strength level (gain of 14.7 per cent in warp and 21.5 per cent in filling direction) is attributed to the change in the dyeing process alone (see part IV).[6]

RESUME—PART I

To sum up the foregoing data on variations in piece goods production, certain general conclusions which hold true for both worsted and woolen pieces may be drawn. Within one piece it makes little difference whether we test different groups of yarns or the same groups of yarns repeatedly in the sample area. The variability of tests within one piece is not affected by testing under ordinary mill atmospheric conditions or controlled laboratory conditions.

Much larger differences were found between tests on successive pieces than in the tests within one piece. This is in accordance with the theory that adjacent specimens of textile materials tend to have the same properties.

---

[6] See p. 938.

When groups receiving the same treatment are plotted on control charts, inherent variations from group to group, within well defined limits, are evident. When new sources of variability make themselves felt, the control charts reflect the movement of the averages toward the new level at which stability may be reached.

In the case of the serge pieces, the four definite levels shown demonstrate:

1. Average strength of 153.8 lb. in warp and 121.5 lb. in filling.

2. A loss of strength (9 per cent) through the introduction of the sanding operation. Accompanying this strength change was a reduction of the pieces passing specifications from 96 per cent to 62 per cent. A new strength level was established at 145.7 lb. in the warp and 111.1 lb. in the filling.

3. Partial correction of the low level was achieved by control of sanding and use of a coarser yarn. A new level approximately the same as the original average developed at 156.2 lb. for warp and 119.5 lb. for filling. It will be demonstrated later, how much of the change in strength level is due to the coarser yarn.

4. Finally, a change in blend achieved the desired result of no pieces below specification. This new level was at 163.6 lb. in warp and 130.0 lb. in filling.

The melton cloth testing resolved itself along the same lines as the serge. There were two main groups illustrated. The first, average production, had a warp strength level at 63.1 lb. and filling at 52.0 lb. About 9 per cent of the pieces failed to meet specifications. The effect of changing the dyeing process from indigo bottom and chrome top to all indigo is shown by a radical increase in average strength and variability. The second level, at which no pieces fall below specifications, is 72.4 lb. for warp and 63.2 lb. for filling. Further details of the effect of dyeing on strength will be found in Part IV.

PART II—YARN BREAKING STRENGTH

We have previously mentioned that variations in the breaking strength of pieces may be traced back to the yarn. How great are yarn variations and what is their ultimate influence? With these considerations the yarn becomes one of the major factors influencing the strength of the pieces not only with regard to their uniformity but also their relative strength levels. A clear knowledge of the factors which influence the yarn breaking strength is, therefore, a necessity if the manufacturer wishes to avoid weak pieces.

For this phase of our problem various investigations into the direction and magnitude of variations that may influence the yarn breaking strength were conducted. Because of the direct relationship between yarn count and yarn strength, that is, the proportionate increase in yarn strength with an increase in yarn cross-sectional area, these will be presented together.

In this connection, the term "finer" will be used to mean that the yarn is smaller in diameter; the term "coarser" will be used to mean an increase in diameter. This is necessary to eliminate confusion arising from the present reciprocal yarn numbering systems (metric, worsted, runs, etc.) in which higher numbers mean finer yarns and lower numbers mean coarser yarns.

For the convenience of readers unfamiliar with the metric counts, the equivalent worsted (560 yd. per lb.)

and woolen runs (1600 yd. per lb.) are given. The Grex system equivalents are also given. This convenient new system calculates its yarn numbers on the basis of the weight in grams of ten thousand meters length. Therefore, higher Grex yarn numbers mean coarser yarn.

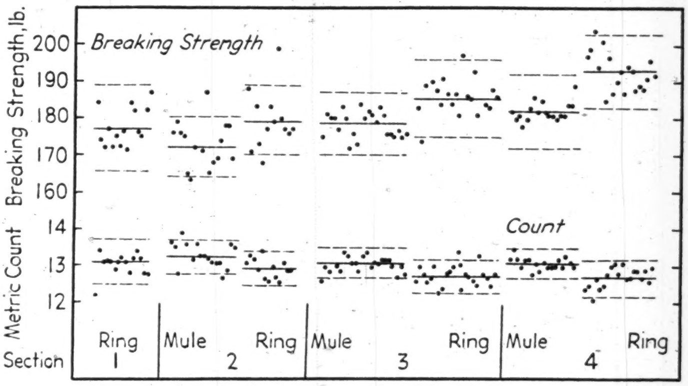


FIG. 5.—Control Chart for Worsted Yarn.

TABLE VI.—VARIATIONS WITHIN SINGLE AND TWO-PLY WORSTED YARNS.

Bobbin	Strength, lb.							Metric Count						
	Test No. 1	Test No. 2	Test No. 3	Test No. 4	Test No. 5	Average	Standard Deviation	Test No. 1	Test No. 2	Test No. 3	Test No. 4	Test No. 5	Average	Standard Deviation
SINGLE YARNS														
No. 1	70.0	72.0	71.0	68.0	69.0	70.0	1.58	25.0	24.8	24.8	25.4	25.8	25.2	0.44
No. 2	68.5	65.5	63.0	64.0	63.5	64.9	2.22	26.8	26.5	26.0	26.6	26.8	26.5	0.33
No. 3	61.5	68.0	68.0	62.5	69.0	65.8	3.51	27.0	25.8	26.8	26.4	25.4	26.3	0.67
No. 4	69.0	64.0	67.0	66.5	66.0	66.5	1.80	26.2	27.0	26.2	27.4	26.8	26.7	0.52
No. 5	66.0	65.0	67.0	68.0	65.0	66.2	1.30	26.2	26.6	26.4	26.6	26.4	26.4	0.17
No. 6	70.5	71.0	68.0	65.0	67.0	68.3	2.49	26.0	26.0	27.3	27.0	26.8	26.6	0.59
No. 7	69.0	68.5	63.0	67.0	68.0	67.1	2.41	26.2	26.6	26.4	26.0	25.8	26.2	0.32
No. 8	70.0	67.5	67.0	66.0	65.5	67.2	1.75	26.2	26.8	27.0	26.6	27.0	26.7	0.33
No. 9	69.0	69.5	67.0	63.5	69.5	67.7	2.57	26.2	26.0	25.8	26.2	25.8	26.0	0.20
No. 10	66.5	65.0	68.5	64.0	66.0	66.0	1.70	27.0	27.6	26.8	27.0	27.0	27.1	0.30
Average	68.0	67.6	67.0	65.5	66.9	67.0		26.3	26.4	26.4	26.5	26.4	26.4	
Std. Dev.	2.71	2.72	2.41	1.99	1.99	1.45		0.58	0.77	0.72	0.57	0.60	0.51	
TWO-PLY YARNS														
No. 1	165.0	162.0	160.0	160.0	162.0	162.0	2.06	13.5	13.6	13.6	13.6	13.6	13.6	0.07
No. 2	171.0	165.0	162.0	164.0	179.0	168.2	6.91	13.0	13.3	12.9	12.9	12.9	13.0	0.17
No. 3	171.0	171.0	167.0	168.0	167.0	168.8	2.05	13.3	13.0	13.1	13.0	13.1	13.1	0.12
No. 4	176.0	177.0	172.0	168.0	163.0	171.2	5.81	12.7	12.8	13.0	13.0	13.1	12.9	0.17
No. 5	157.0	166.0	165.0	162.0	158.0	161.6	4.04	13.9	13.4	13.3	13.5	13.4	13.5	0.24
No. 6	165.0	168.0	166.0	165.0	174.0	167.6	3.78	13.4	13.4	13.3	13.3	13.2	13.3	0.09
No. 7	164.0	158.0	160.0	166.0	161.0	161.8	3.19	13.7	13.4	13.7	13.6	13.9	13.7	0.19
No. 8	167.0	174.0	171.0	171.0	169.0	170.4	2.61	13.3	13.2	13.1	13.3	13.1	13.2	0.10
No. 9	168.0	160.0	168.0	168.0	175.0	167.8	5.31	13.0	13.3	13.2	13.2	12.9	13.1	0.17
No. 10	178.0	184.0	186.0	180.0	175.0	180.6	4.45	12.4	12.6	12.4	12.4	12.3	12.4	0.11
Average	168.2	168.5	167.7	167.2	168.3	168.0		13.2	13.2	13.2	13.2	13.1	13.2	
Std. Dev.	6.12	8.11	7.65	5.52	7.20	5.66		0.46	0.31	0.37	0.37	0.42	0.38	

In this paper any reference to yarn size will be made by using the metric system (496 yd. per lb.) with the letter "m" denoting meters per gram.

The A.S.T.M. method of designation of multiple yarns is followed. The word "plied" is used to indicate two single yarns which have been twisted around each other.

WORSTED YARN

The control charts for serge yarn production, Fig. 5, are constructed similarly to those for the serge pieces. In fact the various sections represent the yarn which went into production of the pieces shown in Fig. 1. Since both ring and mule spinning machines were used in the serge fabric, these sections are divided into two parts with the tests on ring-spun yarn preceding those on mule-spun yarn. Below the control charts for yarn strength, the parallel fluctuations of yarn count are shown.

TABLE VII.—EXTREMES OF COUNT—STRENGTH VARIATIONS IN WORSTED YARN.

		Number of Bebbins	Fine	Coarse
Singles......	Strength average	8	64.5 lb.	74.5 lb.
	Count average	8	27.6 m.	24.8 m
After Plying..	Strength average	4	164.5 lb.	179.9 lb.
Final.......	Count average	4	13.5 = 2/27.0 m.	12.4 = 2/24.8 m.

In the discussion of the piece strength, it was pointed out that the variations exist not only between different groups of pieces but also within these groups. It was further shown that variations could be found in each individual piece. A similar picture presents itself in yarn production. We find that a lack of uniformity not only exists between various groups of yarns, that is, lots, but that variations are also present within yarns produced on one machine and even within each bobbin. The variations within the yarn on the bobbin must be from two sources; first, the fluctuations in count of the singles yarn, second, the differences introduced by plying the two singles yarns.

These variations within one bobbin are presented by the tabulation of the actual data in Table VI. The observations for strength and count on ten bobbins from one doff of one ring spinning frame are given. The last 500 meters spun on each bobbin were divided in five 100-meter skeins. The tests are numbered in the order in which the yarn was spun. The top half of this table illustrates the variations within single yarns; the bottom half covers the fluctuations found in plied yarn.[7]

A special investigation into the possible variations between yarn count and strength was developed as follows: Two hundred bobbins of single yarn were analysed for count. The eight finest and the eight coarsest bobbins were segregated. The yarn strength resulting from plying four pairs of fine singles yarns was 164.5 lb. at an average count of 13.5 m. The plying of four pairs of coarse singles yarns produced a yarn with a strength of 179.9 lb. at an average count of 12.4 m., see Table VII. That this condition of high and low strength is not one which occurs only in laboratory experiments is demonstrated by the end portions of the curves for yarn strengths as seen in Fig. 7.

To further illustrate the variations in one ring spinning frame, a study was conducted on a sample of 100 bobbins of ply yarn intended for regular serge pieces. This yarn was from the same doff mentioned above. The average strength of these bobbins was 169.3 lb. with a standard deviation of 6.3 lb. The average count was 13.2 m. with a standard deviation of 0.32 m.

In order to show the strength distribution of this selected set of 2-ply bobbins, the cumulative curve plotted on probability paper is given in Fig. 6. The strength points fall into a nearly straight line indicating, much the same as the data for piece strength, the tendency toward normal distribution.

---

[7] These 10 ply yarn bobbins are related to the ten singles bobbins only in that they are from the same doff.

As previously mentioned, both mule and ring spinning machines were used for serge yarn production; it must, therefore, be kept in mind that when

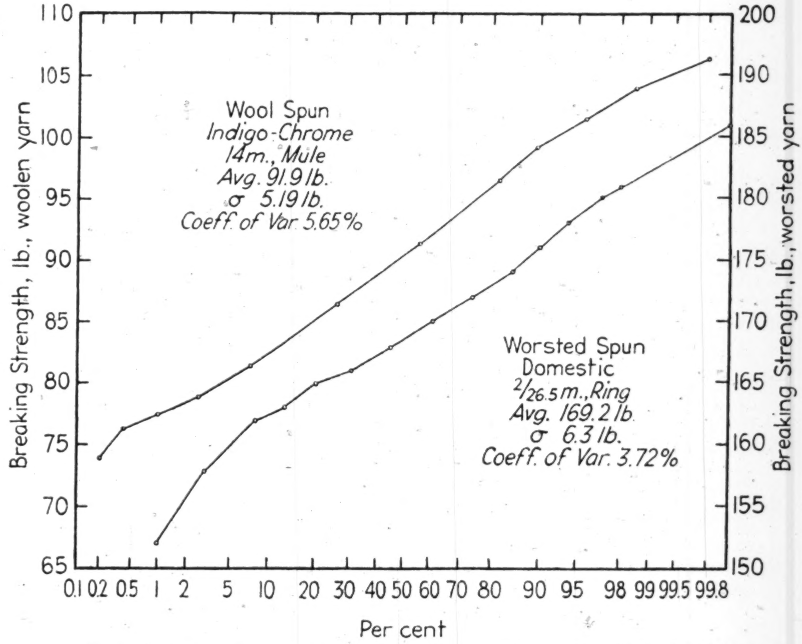


Fig. 6.—Cumulative Curve of Variations Among Worsted and Woolen Yarns.

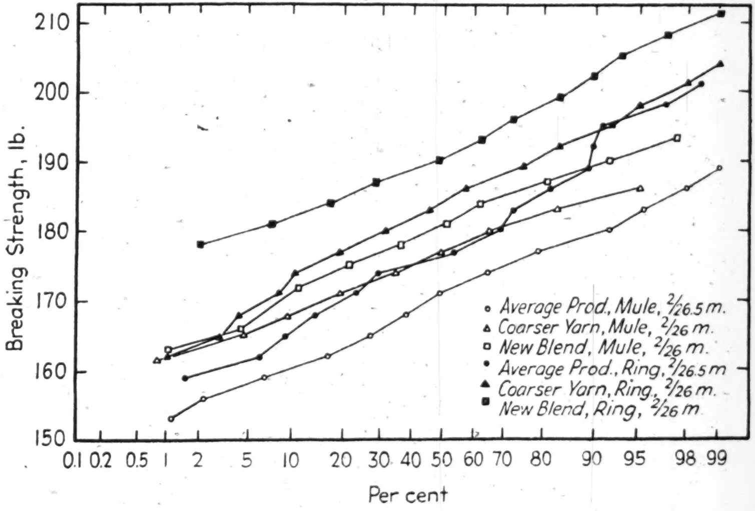


Fig. 7.—Cumulative Curve, Worsted Yarn Strength.

variations among bobbins are discussed we are dealing with two methods of spinning yarn. Is there any difference in strength and variability between the two products? Sixty-five bobbins from each machine type were tested once for strength and count. Table VIII gives the data of this test.

Analysis of the averages and standard deviations indicates that the strength level is significantly different but that the two standard deviations are not. It can, therefore, be said that the ring spun yarn is stronger than mule spun yarn. But look at the count. The ring yarn is approximately 0.3 count coarser than the mule yarn. How much of the strength difference is therefore due to this count difference? The effect of difference in count was removed in the following experiment. Fifty bobbins of mule-spun yarn which had an exact count by test of 13 m. were compared with 50 bobbins of ring-spun yarn which had an exact count by test of 13 m.

	Ring Spun	Mule Spun
Strength, lb.	183.4	179.2
Standard deviation, lb.	7.02	5.62

TABLE VIII.—VARIATIONS BETWEEN MACHINES.

	Ring Spinning	Mule Spinning
Average breaking strength, lb.	179.3	171.4
Standard deviation, lb.	7.79	6.48
Coefficient of variation, per cent	4.34	3.78
Average count, m.	13.0	13.3
Standard deviation, m.	0.40	0.42
Coefficient of variation, per cent	3.08	3.17

This test proves that the ring-spun yarn is significantly stronger than the mule-spun yarn (2.2 per cent). The comparison of the variations within each group shows that the yarns are not significantly different in their variability.

The extent of these variations in yarn strength is brought out by cumulative curves (Fig. 7). All curves show a total range of approximately 40 lb. regardless of spinning machine or wool blend. They indicate definitely the higher strength level of ring-spun yarn over mule-spun yarn. In most cases the points fall in a fairly straight line. The deviations from such a line indicate that the data come from a population which may be somewhat different than a true normal distribution.

Samples of yarn production from the second, third, and fourth sections of the control charts, Fig. 5, were analyzed. The data are shown in Table IX. The strength superiority of ring yarn over mule yarn is shown to exist also when the product of many machines is sampled. The variability of yarn from the two spinning systems as shown by these production samples is practically the same.

TABLE IX.—YARN STRENGTH STATISTICS—WORSTED SPINNING SYSTEM.

Section	Wool Type	Yarn	Ring Spun				Mule Spun			
			Sample Size	Average, lb.	Standard Deviation, lb.	Coefficient of Variation, per cent	Sample Size	Average, lb.	Standard Deviation, lb.	Coefficient of Variation, per cent
2	Domestic	2/26.5 m.	65	179.4	9.84	5.48	90	172.2	7.8	4.53
3	Domestic	2/26 m.	95	185.4	8.73	4.71	105	178.2	6.3	3.53
4	New Blend	2/26 m.	95	193.1	6.49	3.36	90	182.2	7.21	3.96

The extent of the possible variations of individual yarns within the control chart groups is found by calculating the 6-σ range. For the 2/26.5 m. ring spun yarn of section 2, the greatest range we may expect to find is 59 lb. between bobbins. The smallest range, that of the mule spun 2/26 m. yarn of section 3, is 38 lb. In actual production testing, the usual range between bobbins is 30 to 40 lb.

The strength variations previously mentioned comprise the main influence which caused the points on the control chart to fluctuate. By separating the major influences into their component parts the relationships between various producing sections of the mill can be demonstrated. The control chart for the serge yarn production is given in Fig. 5. The first section represents average production. The second section, the yarn which went into the sanded pieces, is also average production. Here the difference between mule and ring spinning is brought out as there were no mule spinning data available for the first section. The third section demonstrates the strength level of a somewhat coarser yarn. It can be seen that the coarser mule-spun yarn is now as strong as the previous ring-spun yarn. The gain in strength over the previous section average is 6.5 lb. (3.8 per cent) for mule-spun yarn. The coarser ring-spun yarn is also 6.5 lb. (3.6 per cent) stronger than the previous average. The last section demonstrates the effect on yarn strength of the introduction of Australian wool as a new blend without change in yarn count. The mule-spun level is 3.5 lb. (2 per cent) higher and the ring-spun yarn is 7.5 lb. (4 per cent) higher than the previous section. In comparison with the original production average, the new blend shows an increase of 10 lb. (5.8 per cent) for mule-spun yarn and 14 lb. (7.8 per cent) for ring-spun yarn. Table X gives the strength levels and expected ranges of fluctuations for the control chart points.

The higher strength level of ring-spun yarn over mule-spun yarn is shown in every case. The introduction of Australian wool in the blend raises the strength level of the yarn itself. The increase in strength is mainly due to the greater length. The average fineness of the blend is about the same as for the 100 per cent domestic wool. The fiber length of the blend, however, is 0.85 in. longer than that of the domestic wool. This greater length gives increased friction from fiber to fiber within the yarn before actual breaking occurs. Shorter fibered yarns possess less fiber-to-fiber friction. It is interesting to note that the blend spun on mules is approximately equal in strength to the 100 per cent domestic wool spun on ring frames (section 3) even though it is approximately 0.5 count finer.

TABLE X.—AVERAGES AND RANGES OF WORSTED YARN CONTROL CHART.

	Section 1	Section 2		Section 3		Section 4	
	Ring	Mule	Ring	Mule	Ring	Mule	Ring
			STRENGTH				
Strength average, lb.	177.3	172.2	179.4	178.2	185.4	182.2	193.1
Point range, lb.	±11.7	±7.8	±9.4	±8.6	±10.6	±10.0	±9.7
			COUNT				
Count average m.	13.10	13.25	12.95	13.10	12.75	13.10	12.70
Point range m.	±0.60	±0.45	±0.45	±0.42	±0.45	±0.40	±0.47

WOOLEN SYSTEM

The same general relations as found for worsted yarns hold true for yarn produced on the woolen system.

The layout used for making the Navy

cloth had a 14 m. (4.33 run, 715 grex) yarn in the warp direction and 16 m. (4.96 run, 625 grex) yarn in the filling direction. The relation of higher warp strength is thereby achieved.

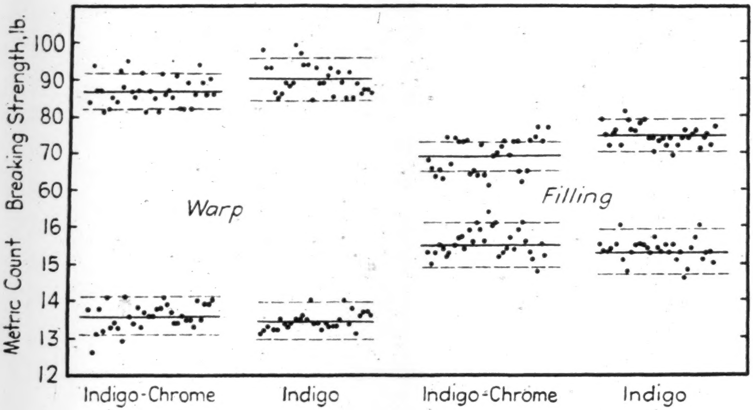


FIG. 8.—Control Charts for Woolen Yarn.

TABLE XI.—VARIATIONS WITHIN BOBBINS OF 14.0 m MULE SPUN WOOLEN YARN.

Bobbin	Test No. 1	Test No. 2	Test No. 3	Test No. 4	Test No. 5	Average	Standard Deviation
			STRENGTH, LB.				
No. 1	104.0	104.0	84.0	80.5	84.0	91.3	11.68
No. 2	88.5	85.5	79.5	82.0	82.0	83.5	3.52
No. 3	95.0	90.5	93.5	95.5	89.0	92.7	2.84
No. 4	88.0	88.0	94.5	95.5	88.5	90.9	3.77
No. 5	99.0	101.0	100.0	100.5	104.5	101.0	2.09
No. 6	82.5	86.5	88.0	97.5	94.5	89.8	6.10
No. 7	86.5	84.0	93.5	91.5	89.0	88.9	3.80
No. 8	89.5	93.5	92.0	95.0	92.0	92.4	2.04
No. 9	89.5	87.0	89.0	95.0	88.0	89.7	3.11
No. 10	91.5	80.5	90.0	88.0	87.0	88.3	4.35
Average	91.4	90.1	90.4	92.1	89.9	90.9	
Standard deviation	6.32	7.46	5.76	6.61	6.25	4.42	
			METRIC COUNT				
No. 1	13.4	13.2	15.3	15.1	15.2	14.4	1.04
No. 2	14.7	15.1	15.6	15.5	15.4	15.3	0.37
No. 3	14.3	14.6	14.2	13.8	14.4	14.3	0.3
No. 4	14.7	14.9	14.4	14.1	14.4	14.5	0.31
No. 5	13.9	13.7	13.6	13.4	13.2	13.6	0.27
No. 6	15.1	14.7	14.2	13.3	13.2	14.1	0.84
No. 7	14.9	15.0	14.5	14.2	14.2	14.6	0.39
No. 8	14.5	14.5	14.1	14.1	14.2	14.3	0.2
No. 9	14.7	14.6	14.4	14.2	14.8	14.5	0.24
No. 10	14.4	15.1	14.4	14.4	14.4	14.5	0.32
Average	14.5	14.5	14.5	14.2	14.3	14.4	
Standard deviation	0.5	0.62	0.58	0.68	0.73	0.42	

Data from testing yarn spun on woolen mules were used. Ring frames were used for some production but in the filling direction only. The small amount of data available for these yarns made it advisable to omit them from the discussion.

In the same fashion as for serge, the parallel fluctuations for yarn count are shown below the control chart for yarn strength. It was necessary to test yarn from wool spinning production in the spinning room where varying conditions of temperature and humidity exist. Figure 8 is the control chart for these yarns. The chart is divided into four sections as follows: Indigo-chrome warp yarn, 14 m.; Indigo warp yarn, 14 m.; Indigo-chrome filling yarn, 16 m.; and Indigo filling yarn, 16 m. Below each section is the corresponding control chart for count.

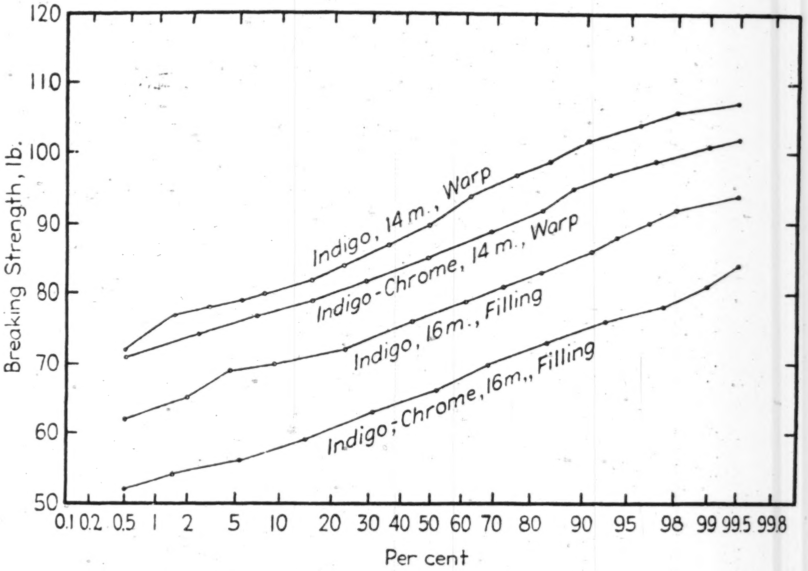


FIG. 9.—Cumulative Curves, Woolen Yarn Strength.

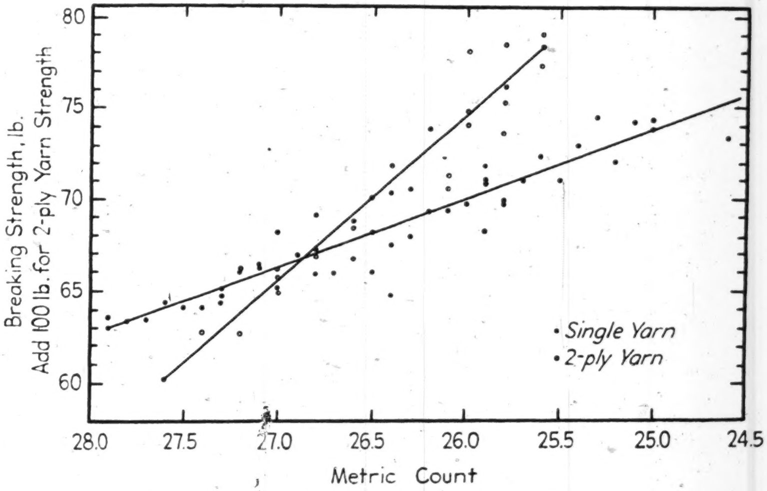


FIG. 10.—Strength *versus* Count, Worsted Yarns.

The difference between successive points in the control graph leads us to seek the sources of these variations—

are they differences between group averages only or do they lie within the yarns? The results shown in Table XI, obtained on 10 bobbins from the same doff of mule-spinning frame, illustrate different strengths found in testing successive lengths of yarn from one bobbin. The differences from bobbin to bobbin are also shown.

To develop the analysis of the differences among bobbins and at the same time show the variations existing within the product of one machine, the following investigation was made: 100 bobbins from one doff of 14 m. 100 per cent cape wool yarn with **Z**48 twist were selected. Each bobbin was tested five times. The wool had been stock dyed indigo bottom, chrome top. The statistics of these bobbins were:

Strength	91.9 lb.	Count	14.2 m.
Standard deviation	5.2 lb.	Standard deviation	0.5 m.

TABLE XII.—WOOL SPINNING SYSTEM—YARN STRENGTH STATISTICS.
Mill Testing Conditions

	Warp 14 m.				Filling 16 m.			
	Sample Size	Average, lb.	Standard Deviation, lb.	Coefficient of Variation, per cent	Sample Size	Average, lb.	Standard Deviation lb.	Coefficient of Variation, per cent
Indigo chrome	340	86.8	6.61	7.66	320	69.1	5.98	8.65
Indigo	300	89.8	7.74	8.6	310	74.6	6.47	8.67

The strength levels of this study are different from the yarn levels given in Table XII because of different testing conditions. The strength distribution of this special study is shown as a cumulative curve in Fig. 10. With the above standard deviation (5.2 lb.), extremes of at least 76.4 lb. and 107.5 lb. are expected. That these extremes actually exist in production is shown in cumulative curves, Fig. 9.

For better illustration of the distribution of strengths found in yarn from various machines, the individual test values from the sections of the control chart, Fig. 8, were plotted as cumulative curves. The percentage of items below any strength level may be read following the instructions given in the section on serge. The ranges indicated by the cumulative curves are approximately 33 lb. in each case. From the standard deviations given below, a theoretical range of approximately 40 lb. is expected. The statistics showing the overall variations in yarn strengths from wool spinning production are given in Table XII.

The same relation between levels is found in this yarn production analysis as was found in the pieces themselves (Fig. 3). Since the standard deviation of the warp and filling yarns indicates that there is no significant difference (*Z* test), it can be said that there is no difference in variability between spinning the two different counts. The relative dispersions of the two yarns are about equal. This is shown by the similarity of the coefficients of variation.

The variations experienced in grouping these tests on control charts, which indicate the fluctuations in production from many machines, are shown in Fig. 8. The strength levels of the sections indicate clearly the same effect of dyeing method which was demonstrated in the piece control charts. The levels and expected limits of point variation are shown below:

Section	Number Points	Warp		Filling	
			Range for 10 Piece Points		Range for 10 Piece Points
STRENGTH					
1	34	86.8 lb.	± 4.9 lb.	69.1 lb.	± 4.1 lb.
2	30	89.8 lb.	± 5.6 lb.	74.6 lb.	± 4.4 lb.
COUNT					
1	34	13.6 m.	± 0.5 m.	15.5 m.	± 0.6 m.
2	30	13.45 m.	± 0.5 m.	15.3 m.	± 0.6 m.

The 14 m. indigo dyed yarn is 3 lb. (3.5 per cent) stronger than the indigo chrome yarn. The strength of the 16 m. indigo dyed filling yarn is 5.5 lb. (7.9 per cent) greater than the indigo chrome dyed yarn. As the yarn count levels show, part of the increase in warp yarn strength is due to a slight increase in coarseness in both warp and filling.

RESUME—PART II

In the analysis of the various factors which affect the yarn breaking strength, it has been demonstrated that small differences exist from length to length along the individual yarns. These differences are due to the complexity of factors involved in the passage of the roving or sliver through the carding, combing, preparing operations, plus those which are introduced in the actual spinning of the yarn itself. From machine to machine these variations are approximately the same within one spinning system as long as the same wool is being used. The fiber length of the wool has a certain undetermined influence upon the variations within the yarn. The way the wool is dyed has been shown to change the variability within yarns.

There is a definite difference among bobbins when the two types of spinning are considered. The relative dispersion of strength tests (coefficient of variation) on worsted spinning is from 3 to 5 per cent while on wool spinning it is almost twice as high, ranging from 7 to 9 per cent. However, a significant difference was not found in standard deviation between worsted ring spinning and worsted mule spinning.

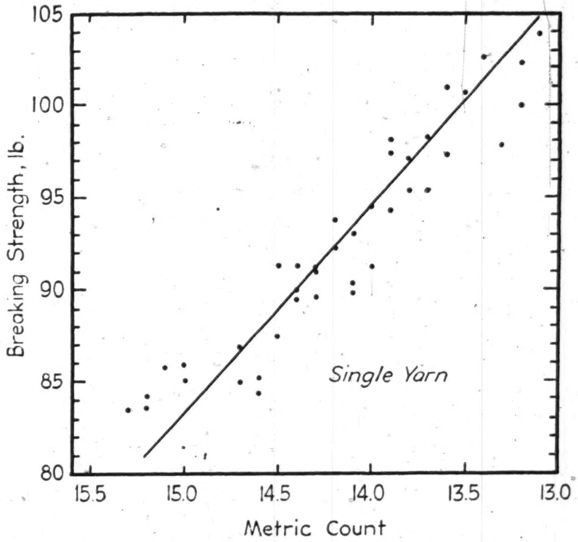


FIG. 11.—Strength *versus* Count, Woolen Yarns.

Therefore, with the exception of the influence of the wool blend and the dyeing method, the above-mentioned variations of strength are more or less of a nature which may be called assignable but uncontrollable causes.

The grouping of bobbin sample strengths on the control charts with their accompanying count figures gives the clue to the source of major variability in yarn production. There is such strong effect of count on strength that this becomes probably the most important of all. It is a well-known fact that coarse yarns are stronger than fine yarns. The relation, therefore, between count and strength should be one that can be demonstrated by graphic means.

The relationship of strength and count for the worsted and woolen yarns is shown in Figs. 10 and 11. The data used for these curves are the 100 bobbin studies already mentioned (Fig. 6). In Fig. 10 the line of best fit is shown for singles and plied worsted yarn. The ratio of strength increase to count increase is logically larger for ply yarn than it is for single yarn. The number of pounds increase for each 0.1 count interval increase is 0.4 lb. for the single yarn. The rate of strength increase for two-ply yarn is 0.9 lb. per 0.1 count interval increase.

A similar relation between count and strength on wool spun yarn is shown by the line of best fit, Fig. 11. Here with the coarser yarn there is an even greater ratio. The change is 1.16 lb. per 0.1 count interval.

The equations for the above lines of best fit are as follows:

Singles worsted...... 1/26 m. $Yc = 70.0 + 0.378\,X$
Worsted............. 2/26 m. $Yc = 174.6 + 0.884\,X$
Wool spun............14.2 m. $Yc = 92.25 + 1.16\,X$

where Yc = the calculated strength in pounds, and
X = one interval of 0.1 m. count,

the third member of the equation is the observed average strength at average count.

In general, therefore, the same relation of increasing strength with increasing yarn coarseness holds true for all yarns disregarding blends, twists, and plies. The above is limited in its application to a fairly narrow range of a few counts above and below the average. It is certain that the tests shown here are only a small part of the long curve of best fit which represents all possible yarn count and strength relations. This curve is not a straight line.

Part III—Effect of Twist on Breaking Strength

A further consideration in the manufacturing of yarn for military fabrics is the amount of twist the yarn should have. The specifications for the serge state that the yarn shall have sufficient twist to insure a character of cloth as shown by the standard sample. The governing factor for selection of twist is, therefore, the appearance of the finished cloth. The effect of twist on strength is usually neglected though spinners know that it has a definite influence.

In order to evaluate the effect of twist on strength and count, tests were conducted on both worsted and woolen yarn.

Worsted

The basis for demonstrating change in strength was a 2-ply yarn with zero turns. This was developed by testing[8] 20 bobbins of ring spun 1/26 m. **Z**40 yarn from one doff for count and breaking strength, then doubling without twist

TABLE XIII.—RELATION BETWEEN STRENGTH AND TWIST—WORSTED YARN.

26 m. Ring Spun.

	Number of Bobbins	Average Strength, lb.	Increase over Base Strength, per cent	Actual Twist, turns per 10 cm.	Count, metric
Singles	20	72.4		**Z** 48	25.8
Doubled	10	146.	100.0[a]	0	12.9
20T ply	15	157.5	7.8	**S** 19.6	13.1
30T ply	15	170.3	16.7	**S** 29.5	13.1
40T ply	15	181.4	24.2	**S** 39.1	13.0
50T ply	15	185.1	26.8	**S** 48.9	12.9
60T ply	15	186.6	27.8	**S** 60.1	12.6

[a] Base.

---

[8] A steaming operation is necessary to equalize the stresses set up by twisting. The bobbins are passed through a steaming machine 10 min. at 160 F. then allowed to rest 24 hr. in the conditioned testing room—65 per cent relative humidity and 70 F.—before testing.

and retesting. The figures are given in Table XIII. Any change in strength that results from twisting the plies about each other will therefore be the result of the twist itself.

Thirty bobbins of the same yarn as above were picked at random from the same doff. Each bobbin was tested four times (100-meter skeins) for strength and count, selecting the bobbins at random from a large basket.

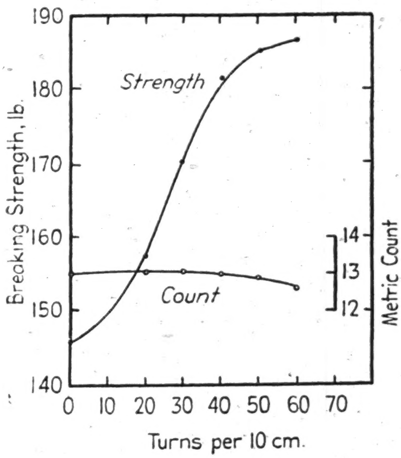


FIG. 12.—Strength *versus* Twist, Worsted Yarns.

After the strength and count of the individual bobbins were established, pairs of bobbins in the random order of testing (1 + 2, 3 + 4, etc.) were plied together in successive groups of gradually increasing **S** turns per 10 cm. In order that these various twist groups could be identified, each was put on a bobbin as a separate independent length; thus the first layer was 330 Meters long with a specified twist of 20 turns, the second layer was 330 M long with a specified twist of 30 turns, etc. See Table XIII. Fifteen bobbins of two-ply yarn for each of the five specified twists were thus produced.

The number of tests that could be made was limited by the length[9] of yarn available on each singles bobbin as it was not considered desirable to utilize yarn from other bobbins in this test. Each twist group permitted only three tests for count and breaking strength on each bobbin giving a total of 45 tests each for count and strength of each specified twist. In order to determine how accurately the specified twist had been met, the actual twist of each layer was also measured. This is shown as a separate column in Table XIII.

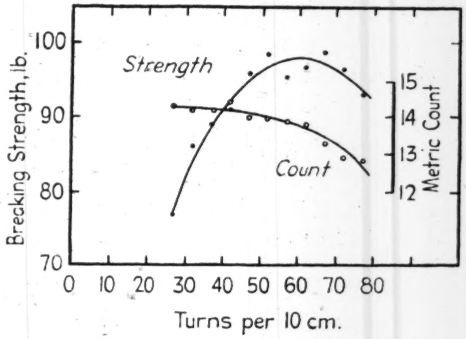


FIG. 13.—Strength *versus* Twist, Woolen Yarns.

The data show that the breaking strength increases greatly up to about 50 turns. After 50 turns, the curve of strength increase flattens out. The maximum strength is reached at 60 turns, which was the end of the test (see Fig. 12). There was an increase in strength by twisting of 27.8 per cent over the parallel pair of singles yarns.

WOOLEN YARN

The same investigation was conducted on single 14-m. mule-spun woolen yarn (see Fig. 13). In this case an unlimited length of roving was available so that closer steps of twist increase could be made. Twenty bobbins were prepared for each twist starting at **S**27 per 10 cm.

---

[9] Approximately 2100 meters.

and increasing to **S**77 in steps of five turns. Each bobbin was tested 5 times for twist, once for count, and once (100 meters skein) for strength (see Table XIV).

TABLE XIV.—RELATION BETWEEN STRENGTH AND TWIST—WOOLEN YARN.

14 m. mule spun.

Turns	Number of Bobbins	Average Strength, lb.	Base Strength, per cent	Actual Twist, turns per 10 cm.	Count, metric
27....	20	76.8	79.2	27.1	14.3
32....	20	86.1	88.7	30.9	14.2
37....	20	89.1	91.8	37.2	14.2
42....	20	91.1	93.9	41.5	14.4
47....	20	96.3	99.3	45.3	14.0
52....	20	97.0	100.0[a]	51.2	13.9
57....	20	95.4	98.4	54.7	13.9
62....	20	96.8	99.8	60.4	13.8
67....	20	98.8	101.7	63.5	13.3
72....	20	96.5	99.5	70.6	12.9
77....	20	93.0	95.9	75.6	12.8

[a] Base

The curved relation between twist and strength indicates very clearly that the maximum strength which may be achieved is approximately 100 lb. There is a definite break in this curve with resulting loss in strength due to the effect of overtwisting. As the amount of over-twist increases, the strength loss becomes progressively greater.

The two curves shown in Figs. 12 and 13 were smoothed to equalize sampling fluctuations. The uniformity of the wool roving is such that it yields a somewhat more variable product.

From the above curves it can be seen that small variations of twist number around the normal (that figure which has been found by experience to be satisfactory) cannot have any great influence on the strength. A definite end point for practical strength increase exists for each yarn size. Twisting to this optimum gives the best spinning production when strength is the only consideration.

As more and more turns of twist are inserted into the yarn, the count becomes rather uniformly heavier due to the take-up. This effect could not be demonstrated clearly in the ring-spun worsted yarn trials. The superimposing of an **S** twist in plying upon a **Z** twist in the singles yarn reduces the singles twist and, therefore, changes the count of the individual plies. In the woolen yarn there is no complicating effect of the ply twist; therefore, the change in count with change in twist is clear.

To sum up the effects of variations in twist on strength: the small differences in twist as would occur in normal production have no influence at all upon the strength of the yarn. It is only when large differences in twist occur that an effect on yarn strength and count can be found.

PART IV—INFLUENCE OF DYEING ON STRENGTH

It has long been known that dyeing techniques have a great influence on strength of dyed wool. Of the two main methods used in applying chrome colors, the top chrome and the metachrome method, the latter is generally accepted today as the better when the preservation of strength is paramount. In this study we have an additional proof of this effect on worsted goods.

In stock dyeing of navy blues, one of the oldest disputes is whether indigo or vat colors as opposed to chrome colors should be used. The war has again brought this question to the fore and a clear answer is given in this paper without equivocation. From the levels shown in the melton control charts, it is apparent how much stronger indigo dyed wool is than indigo chrome dyed wool.

WORSTED TOP DYEING

Since the worsted top was all metachrome dyed, data from another military fabric, elastique, must be utilized for demonstrating the differences in the two main methods of worsted top dyeing. The dyeing was done in ball form using Longclose machines. Australian top of 21 microns fineness was selected for this trial. The dyeing procedure was as follows:

Top Chrome

Erio chrome azurol BX	2.14 per cent
Erio chrome blue black RZ	0.98 per cent
Alizarol grey CFG	0.89 per cent
Acetic acid, 80 per cent	2.68 per cent
Formic acid, 90 per cent	1.8 per cent
To boil	1 hr.
Boil	1 hr.
Chrome	1.8 per cent
Formic acid 90 per cent	0.5 per cent
Chrome to boil	¾ hr.
Chrome boil	1 hr.
Total	3 ¾ hr.

Metachrome

Alizarine blue black B	0.74 per cent
Erio chrome olive BL	0.94 per cent
Alizarol brown EB	0.45 per cent
Acetic acid, 80 per cent	3.57 per cent
Chrome	1.52 per cent
To boil	1 hr.
Boil	1 ½ hr.
Total	2 ½ hr.

The tensile strength of the fibers from the natural white top and from the above dyed top were tested with the bundle test. The testing results of top, yarn, and pieces are shown in Table XV.

The fiber strength shows clearly the advantage to be gained by using the shorter dyeing time of the metachrome dyeing process. When compared with the undyed top the reduction in bundle strength after $2\frac{1}{2}$ hr. boiling time is 1200 psi. (6 per cent). The top chrome process with $3\frac{3}{4}$ hr. boiling time reduces the strength 3000 psi. (15 per cent). That this strength difference of 9 per cent between metachrome and top chrome dyed top directly affects the yarn and piece strength is clearly brought out by the data. The variation within the tests indicates no significant differences in variability of strength between the two tests though both are significantly larger than the variations in the natural white wool. This is easily understood because the deteriorating influences are not completely uniform on every fiber.

The metachrome dyed filling yarn is 5.4 lb. (6.1 per cent) stronger than the top chrome yarn, which in turn is responsible for 5 lb. (6.4 per cent) increase in the piece strength. The metachrome dyed warp yarn is 5.5 lb. (5.7 per cent) stronger. In the piece the difference amounts to 12 lb. (8.3 per cent). It is probable that part of this large difference is due to sampling fluctuations.

TABLE XV.—STRENGTH-DYEING RELATION.

FIBER STRENGTH TOP

	Natural White	Top Chrome Dyed	Metachrome Dyed
Number of bundles	15	15	15
Average strength, psi	20 000	17 000	18 800
Standard deviation, psi	390	960	880
Dye time, hr	0	3 ¾	2 ½

YARN STRENGTH

	Top Chrome		Metachrome	
	Warp	Filling	Warp	Filling
Number of skeins	10	10	10	10
Yarn count, m.	1/45	1/23	1/45	1/23
Average strength, single yarn, lb.	35.5	87.9	37.4	93.3
per cent	100.0	100.0	105.3	106.1
Elongation, per cent	11.4	16.8	14.7	22.1
Strength after plying into 2/45 m., lb.	95.9		101.4	
per cent	100.0		105.7	
Elongation after plying, per cent	20.1		25.2	
Finished piece[a] strength, lb.	145	78	157	83
per cent	100.0	100.0	108.2	106.4

[a] Average of 5 pieces, 4 tests in each direction.

The influence of dyeing on the physical properties of yarn are further indicated by the figures for elongation. In all cases the shorter dyeing time (metachrome) preserves the elasticity.

STOCK DYEING

The previous trials to produce the required Navy shade stock dyed with chrome colors, proved that the Navy strength requirements could not be met satisfactorily. The few pieces made showed a strength level in the warp between 50 to 54 lb. and a strength level in the filling between 40 to 45 lb., which was in the case of the warp 10.3 per cent and in the case of the filling 8.7 per cent below the specifications. With the introduction of an indigo bottom applied in one dip at a temperature of 140 F., followed with a topping of chrome colors, the strength level rose considerably, but still not completely above specifications, as seen in Fig. 4. However, the continuous process of indigo dyeing on loose wool eliminated the topping with chrome colors and thus the damaging effect of high temperature, and a further rise of the strength level resulted. The indigo process involves 2 dips of 6 min. each in a continuous train constructed similarly to a scouring train. The bath temperature is maintained between 135 and 140 F., and the total processing time is 35 min.

It is interesting to note that the strength superiority of the indigo process over the indigo-chrome process is greater in piece goods than in yarn. The indigo yarn is 3 to 8 per cent stronger while the indigo pieces are 16 to 21 per cent stronger. In the worsted metachrome dyed goods, little difference could be found between yarn and piece strength superiority (approximately 6 per cent).

TABLE XVI.—DYEING PROCESS.

Top Chrome	*per cent*	Indigo-Chrome	*per cent*	Indigo	*per cent*
Blue black BNZ	0.5	Indigo, 1 dip	10	Indigo, 2 dips	40
Chrome red B	3.5	Chrome Topping	*per cent*		
Cyanine RC	0.2				
Brown DKL	0.2				
		Erio chrome blue black RZ	3.0		
		Alizarine blue black B	1.0		
		Monachrome red FGA	0.3		
		Fast chrome red B	1.9		
Acetic acid, 80 per cent	2.7	Acetic acid, 80 per cent	3.0		
Formic acid, 90 per cent	1.8	Formic acid, 90 per cent	0.5		
Chrome	1.8	Chrome	2.0		

BREAKING STRENGTH

Yarn	Mill Specification	Top Chrome	Indigo Chrome	Indigo
Warp, lb.	87	71	87	90
per cent	100	81.6	100.0	103.4
Filling, lb.	72	59	69	75
per cent	100	81.9	95.8	104.1
Pieces	Navy Specification			
Warp, lb.	58	52	63	72
per cent	100	89.7	108.6	124.1
Filling, lb.	46	42.0	52	62
per cent	100	91.3	113.0	134.8

Table XVI gives the details of dyeing process and strength results.

Further reference to the effect of piece dyeing upon strength is made in the next section of this paper.

PART V—VARIOUS OTHER INFLUENCES

Such mechanical influences in design and weaving layout as changes in ends, picks, width in the loom, sizing and not sizing are readily segregated by a knowledge of the manufacturing process involved. Various other influences in finishing were studied with the intention of proving whether certain long-time considerations were valid. Previous figures gave the extent of strength variations in yarn. It is, therefore necessary to determine how piece strength variations are effected by finishing operations. Does finishing enlarge or reduce the range of possible strengths? Does fulling actually make a cloth stronger? What are the effects of final-finishing operations such as decating and pressing?

Samples through finishing were taken before and after major operations. All of these samples were tested under standard conditions of temperature and humidity. The purpose of these was to follow the strength changes from gray piece to finished piece.

FULLING

Fulling is the first operation on both of the gray goods in this study (see flow sheet of cloth manufacture[10]). The results of testing fulled goods indicate definitely that there is no similarity between worsted and wool spun yarns in their strength change in the fulling process (Table XVII). The serge was unchanged or slightly weakened (3 per cent loss in strength) while the more extensively felted melton showed a definite gain in both warp and filling strength. The main function, then, in the fulling of worsted pieces is to develop quality, that is, texture, rather than produce a strength change.

For wool spun pieces the function of fulling is divided between developing texture and strength. As can be seen from the weaving layout of the melton, an increase in pick number from 45 to 55 per inch is required. This amounts to a 22 per cent shrinkage in length. The width must be reduced from 85½ in. in loom to 55 in. finished, equal to 36 per cent shrinkage. The surface character of a melton is such that fiber matting covers the yarns completely. Thus the maximum fiber interlocking (and absolute strength)[11] must be developed by the fulling operation. Table XVII indicates the average gain by fulling in warp strength for stock-dyed pieces is 12 lb. (22 per cent) over the gray strength. The filling gained an average of 10 lb. (20 per cent).

The gray goods used for the piece-dyed melton show a different change in fulling than the wool-dyed goods. As can be seen from the table, the gain over the gray strength is only 16 per cent for warp. The change in filling strength is unexplainably low especially for white goods.

The data of Table XVII give the absolute strength increase or loss of the pieces from gray to finished in terms of pounds per grab test. When these pounds per test are calculated in terms of breaking strength per yarn, an entirely different picture is found. Due to the chemical and physical operations involved in finishing the cloth, there is a loss in strength of the individual yarns. In the serge specifications it was pointed out that there exists a lack of balance in yarn strength demand. The filling is expected to be 17 per cent stronger than the warp. The justification of the criticism of this unbalance is found in the strength per yarn given above. The filling can reach the same load-carrying strength per yarn as the warp but not greater. The serge actually becomes weaker through finishing both in the absolute cloth strength and the relative load-carrying yarn strength. This relative loss amounts to 1.3 per cent in the warp and 3.3 per cent in filling for the 100-per cent domestic wool serge. The blended-wool serge has a loss in relative strength of 10.5 per cent in warp and 3.2 per cent in filling direction. The main reason for the breaking strength loss is the distortion of the fiber parallelism by fulling. The high warp strength loss (10.5 per cent) is probably a fluctuation effect in the small sample available.

---

[10] See p. 918.

[11] Grab test result.

TABLE XVII.—STRENGTH CHANGES IN VARIOUS FINISHING PROCESSES.
(Standard conditions)

	Number of pieces	Gray Strength, lb.		Fulled and Washed Strength, lb.		Carbonized and Neutralized Strength, lb.		Finished Strength, lb.		Relative Loss in Strength, per cent	
		Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling	Warp	Filling
Serge:											
Average production	10	149	124	147	122			152	122		
Strength per yarn		2.40	2.44					2.37	2.36	1.3	3.3
New blend	5	159	128	152	124			157	126		
Strength per yarn		2.68	2.52					2.41	2.44	10.5	3.2
Specifications								1.76	2.04		
Melton:											
Indigo-chrome	10	51	46	62	54	64	54	66	54		
Strength per yarn		1.19	0.98					1.08	0.96	9.3	2.0
All indigo	10	57	53	71	63	70	63	72	62		
Strength per yarn		1.53	1.15					1.18	1.07	7.8	6.9
						Ready to Dye					
Piece dyed melton:											
All chrome	8	55	56	64	58	65	55	61	51		
Strength per yarn		1.28	1.22					1.00	0.89	21.9	27.1
Specifications								0.97	0.84		

Absolute Strength Change in Fulling

	Gain over Gray			
	Warp Strength		Filling Strength	
	lb.	per cent	lb.	per cent
Serge:				
Average production	−2	−1.3	−2	−1.6
New blend	−7	−4.4	−4	−3.1
Melton:				
Indigo chrome	11	21.6	8	17.3
All indigo	14	24.5	10	18.8
Piece dyed melton:				
All chrome	9	16.3	2	3.5

In the case of the melton which is heavily felted, the absolute cloth strength shows a large gain from gray to finished. The loss in relative strength, however, is greater than was observed in the serge. This is probably a direct consequence of the longer melton fulling time: 120

to 210 min., as compared with 45 to 60 min. for the serge. The loss in relative strength amounts to 9.3 per cent in warp and 2 per cent in filling for the indigo-chrome-dyed pieces. The indigo-dyed piece lost 7.8 per cent in warp and 6.9 per cent in filling.

PIECE DYEING

The figures for the piece-dyed melton, indicating a relative loss of 21.9 per cent in warp and 27.1 per cent in filling, are the highest found. The higher relative loss of the piece-dyed melton is probably due to the additional action of the boiling dye bath to the normal change caused by finishing operations. The stock used in these pieces was 100 per cent domestic wool.

Since the wool is domestic rather than Cape and since the pieces are undyed, the gray strength level is slightly different from the indigo-dyed gray pieces. The strength level of the piece-dyed goods in the finished condition is 6 to 8 per cent below its ready-to-dye level. This loss is directly traceable to the piece-dyeing operation. Studies made on civilian styles show that 5 per cent is about the minimum change that will take place. According to the length of dyeing operation (number of additions) the piece strength gradually decreases.

CARBONIZING

The piece-dyed meltons were carbonized after dyeing, whereas the wool-dyed melton was carbonized at a stage equivalent to "ready to dye." Carbonizing before or after dyeing has not been found to make any difference on strength.

The carbonizing was carried out with a controlled minimum amount of sulfuric acid, approximately 5 per cent, which would accomplish destruction of vegetable matter. Oven temperatures (baking at 200 F.) are carefully controlled so as not to burn the wool. The neutralizing process was also controlled so that a minimum of soda necessary to neutralize the acid in the shortest practical time was used. The above controls were found necessary to minimize harmful reactions with consequent increase in variability of production.

SANDING

Figure 1 shows that the effect of sanding upon the average filling strength of serge may be as high as 11 lb. (9 per cent). The effect on the warp is somewhat less (5 per cent). Since the filling fibers lie at right angles to the direction of rotation of the sanding drums, they are readily cut by the sand grains. The warp fibers are more nearly parallel; therefore, less cutting takes place. The same consideration holds true for the napping process using wire-covered napping rolls.

DECATING AND PRESSING

Various practical trials conducted to show the effect of open decating led to the conclusion that this operation, apart from residual moisture, had little or no effect on strength. However, unless the moisture content of the pieces was either controlled or brought to equilibrium under standard testing conditions, wide variations in strength would be attributed to the decating operation. Slight dimensional changes in length and width were found. These simply change the texture, increasing or decreasing ends and picks per inch, thereby altering the strength.

Closed decating on the other hand, which is conducted under steam pressure, produces a definite reduction in strength. While this operation was not in the finishing routine for either of the fabrics in this study, tests on other cloths[12] have shown a reduction in strength of 13 to 14 per cent.

---

[12] Tropical worsted for the Navy, worsted gabardine for the Army.

Cylinder pressing, which is carried out by passing the pieces between a steam-heated rotating cylinder and a fixed curved steam-heated bed, has three influences on strength. The first is that of drying out the piece to a low (2 per cent or less) moisture content with the accompanying reduction in strength due to moisture alone. The second is the stretching of 3 per cent or more, depending upon the clearance between the cylinder and bed. This dimensional change causes a definite reduction in number of picks per inch with consequent reduction in filling strength. The third effect, that of heat, since the cylinders are operated with pressure up to 100 psi. approximately equal to 338 F., is an unknown factor though it could only result in reduction of strength. However, the time of contact (approximately 12 sec.) is rather short for any serious damage to occur as long as the cloth is kept moving.

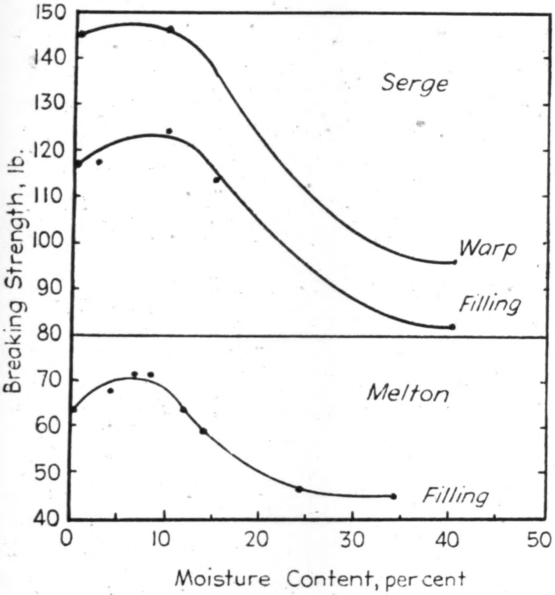


FIG. 14.—Strength *versus* Moisture Content.

MOISTURE

The influence of variations in moisture upon breaking strength has long been known. The curve for melton indicates that between zero and approximately 8 per cent, there is a steady rise in strength as the moisture content increases. From about 8 per cent on, strength rapidly decreases until approximately 25 per cent moisture content is reached; from then on the rate of strength change becomes progressively less until saturation, see Fig. 14. The curves for serge follow approximately the same pattern.

It is thus evident that one of the fundamental factors controlling breaking strength levels is the moisture content of the material being tested. This variation is brought to a minimum under standard conditions. The tests made under mill conditions are, therefore, subject to considerable fluctuations as the relative humidity in the room changes. The moisture content of the cloth from the previous process is an equally important factor. Whenever mill test results were suspected of being unduly influenced by moisture, duplicate samples were submitted to test under controlled conditions. In this way the effect of wide fluctuations on breaking strength were at least partly determined and full weight was not given to a change in strength unless it could be proven to exist under standard conditions.

Even under controlled conditions of 65 per cent relative humidity and 70 F., equilibrium moisture content depends on whether the wool reached its moisture balance from the dry side or the wet side.[13] The moisture content of loose wool or top is approximately 14 per cent when equilibrium is reached from the dry side and approximately 16 per cent when equilibrium is reached from the wet side. In finished fabrics, due to the effect of the various treatments, the moisture absorption or desorption is approximately 2 per cent lower, respectively 12 per cent and 14 per cent.

From frequent tests on samples at the mill testing station, it was found that the moisture content was usually in the neighborhood of 6 to 8 per cent. It is, therefore, evident that the mill testing, quite by accident, was carried out at a moisture level near that of maximum strength.

CONCLUSION

This study of the factors influencing the breaking strength of Army and Navy fabrics shows that the raw material chosen is one of the primary factors. Yarns from fine domestic wools are generally weaker due to their shorter fiber length than Australian or Cape wool yarn of similar fineness. A change in the blend affected the strength level of yarns and pieces as a whole. In the case of a 50 to 50 domestic-Australian wool blend, the strength increased 5 to 8 per cent over that of the 100 per cent domestic blend.

The method chosen to dye the wool or top is another primary factor in the ultimate strength level. The length of time the wool is in contact with the dye bath and the temperature of the dye bath are the two most important factors. In this connection the metachrome dyeing process with its shorter time produced 6 to 8 per cent stronger pieces than the top chrome dyeing process. Continuous indigo dyeing with its short immersion time and low temperature yielded pieces which averaged about 25 per cent above the specified strength. In the case of the indigo-chrome combination the strength level was 10 to 15 per cent above, whereas the chrome dyed wool produced pieces which were approximately 10 per cent below specifications.

The variations introduced into the strength picture by the spinning process are of a varied nature. The yarn count directly affects not only the strength of the yarn itself but also of the fabrics. A change of half a count metric in the two-ply serge yarn resulted in a 4 per cent increase of the yarn strength.

Therefore, control over yarn count, that is, holding yarn fluctuations within small limits, will result in a reduction of the variations in eventual fabric strength. The relationship between single yarn strength and plied yarn strength has been demonstrated. It was shown that the ply worsted yarn, by reason of the doubling twist, is about 25 per cent stronger than twice the single yarn strengths.

---

[13] The determinations for Fig. 14 were carried out from the wet side.

The yarn produced on ring spinning frames is 2 per cent stronger than the yarn spun on mules. The amount of the difference, nevertheless, is not large enough to be of great importance.

The yarn breaking strength varied directly with the amount of twist to a certain maximum. Further insertion of twist then reduced the breaking strength. A definite end point for practical strength increase exists for each yarn size. Small differences in twist within the range that occurs in normal production have little or no influence upon the strength of the yarn. It is only when large differences in twist occur that an effect on the strength will be noticed.

By the comparison of variations of worsted and wool yarn, indications of the inherent manufacturing uniformity levels and variations have been revealed. By reason of the complexity of the worsted yarn system small inequalities tend to be averaged out through the long preparatory processes before actual spinning takes place. This is not the case in the woolen system. Variations in roving off the cards is directly transmitted to the yarn as there are no intervening equalizing operations. Assignable causes of variation of this type, due to the manufacturing process, can be minimized by strict control but not completely eliminated without radical alteration of the process itself.

The foregoing comments upon manufacturing operations previous to weaving indicate that the material with which the weaver has to work is by no means uniform. Since weaving is a combining operation, the yarn variations are carried over directly into pieces and form a part of the ultimate variations found in finished cloth.

In order to bring the factors influencing the breaking strength of Army and Navy cloth to a common ground, the coefficients of variation, that is, the relative variabilities, previously mentioned, are grouped in Table XVIII. The coefficients are completely different for the two spinning systems. Wool spinning has more than twice the variability that the worsted system has. This generalization holds true for the piece goods. The data show that the strength variations in the yarns are directly responsible for the strength variations in the cloth. However, the worsted trend is toward increase in variability as manufacturing progresses. On the other hand, the woolen system trend is the reverse. Evidently, the reaction of the product of wool spinning is toward a loss of variability, that is, gain in uniformity.

TABLE XVIII.—COEFFICIENTS OF VARIATION (PER CENT) THROUGHOUT MANUFACTURING.

	Worsted				Woolen	
	Domestic		Blend			
	Warp	Filling	Warp	Filling	Warp	Filling
Yarn Ring	5.5	...	3.4	...	...	...
Mule	...	4.5		4.0	8.6	8.7
Pieces Gray	4.4	4.0	4.4	4.0	5.8	7.0
Finished	4.3	5.2	4.5	4.4	6.0	8.1

The effect of fulling on worsted pieces is just opposite to that on woolen pieces. While the woolens gain in absolute strength, worsteds remain unchanged or become weaker, but both show a loss when breaking strength per thread is considered.

Carbonizing and neutralizing in piece form, when properly controlled, have very little effect. The effect of surface disturbing operations, such as sanding and napping, can be measured directly by the change in breaking strength. Operations designed to produce a certain touch such as decating and pressing have a complicated influence, the greatest part of which is the moisture content of the cloth when testing is performed under mill conditions.

There is a definite peak strength to be associated with moisture content of approximately 8 per cent. Higher or lower moisture content yields lower strength. The moisture level of control testing at 65 per cent relative humidity and 70 F. is not that of maximum strength.

TABLE XIX.—PREDICTION OF STRENGTH.

	Worsted		Woolen	
	Warp	Filling	Warp	Filling
Yarn strength needed:				
Average	166[a]	180	87	72
Standard deviation	7.0	7.0	8.0	7.0
Gray piece strength needed:				
Average	143	130	55	52
Standard deviation	7.0	6.0	4.0	5.0
Finished piece strength needed to pass specification 100 per cent				
Specification	120	110	58	46
Average	141	128	70	61
Standard deviation	7.0	6.0	4.0	5.0

[a] Actual production = 193 lb.

The vital question of whether the manufacturer can predict his finished piece strength has been answered in the foregoing presentation. It may be summed up in Table XIX.

The results of control testing throughout manufacturing enabled the setting of minimum strength averages to be maintained. The figures above give these levels. The finished piece averages[14] were set high enough so that the normal fluctuations would not cause any piece to fail specifications. The yarn and raw piece averages were then adjusted to give the desired finished piece level. Greater standard deviations than those given necessitate the maintenance of higher average levels whereas smaller standard deviations permit maintenance of an average level closer to the specified minimum. From an economical point of view, this is the goal to achieve.

These observations provided information as to the present state of manufacturing variations and also indicated lines of further research into the fundamental factors causing these variations.

---

[14] According to the standard deviations given; these are 3 sigmas above the specification.

TESTING PROCEDURES

Accuracy Levels—A.S.T.M.

The number of tests is so calculated that the sample size in general gives us a probability of at least 0.90 and a sampling error not exceeding 3 per cent. (See Proposed Recommended Practice for Calculating Number of Tests to Be Specified in Determining Average Quality of a Textile Material A.S.T.M. Standards on Textile Materials, Appendix VI, p. 341 (1943). (Issued as a separate publication.))

The data on test procedure as regards frequency of piece sampling are given in the first part of this paper. The sample sizes used for the pieces, yarn, and fiber references are given below:

1. Fineness	2 to 4 samples of top or roving daily, 100 fibers per sample.
2. Worsted Yarn:	
(*a*) Strength	Five 100 M. skeins—one from each of 5 bobbins = 1 sample. One sample per day. Different spinning machine each day, tested under standard conditions.
(*b*) Twist singles	Four 25 cm. lengths per bobbin from each of 5 bobbins, retwist method. Tested under standard conditions. Reported as number of turns per 10 cm.
Ply	Two 50 cm. lengths from each of 5 bobbins, open twist method. Tested under standard conditions. Reported as number of turns per 10 cm.
3. Wool Yarn:	
(*a*) Strength	Five 100 M. skeins—one from each of 5 bobbins = 1 sample. One sample taken from each doff. Mill conditions for control purposes.
4. Pieces	(*a*) Four tests on warp, four on filling (same group of threads); under mill conditions. Sampling procedure—see part 1. In order to further insure that the previous process had a minimum effect on the strength, a routine was established so that strips of cloth hung from a line for 3 to 4 hours in a large open room before testing. (*b*) Five tests on warp, five on filling (different groups of threads); tested under standard conditions.
5. Machines	Strength: Scott Twist: Suter

The various significance tests used are standard statistical procedures.[3] The "T" test for differences in means and the "Z" test for differences in standard deviations, eliminate the guesswork attached to comparison of these levels. When differences larger than those which could be caused by chances sampling fluctuations (95 per cent probability) are found, it is fairly safe to say that they are "real" and dependable, that is, significant. Since all difference testing rests on sample size, special reference to this factor is made. In some cases no additional samples were available and our conclusions rested upon perhaps what might be considered a small sample.

SHORT-TIME STATIC TESTS AND CREEP TESTS OF A PAPER LAMINATED PLASTIC

By W. N. Findley[1] and W. J. Worley[1]

Synopsis

Short-time tests of a Mitscherlich paper laminate in tension, compression, and torsion show the strength and stiffness of this material under static loads. All static tests were conducted at the same rate of tensile strain, and at a constant temperature of 77 F. and relative humidity of 50 per cent.

Results of long-time tension creep tests of specimens at eight different values of stress are reported. Creep was recorded over a period of 7000 hr. at the same constant temperature and humidity used for the short-time tests. The creep tests are analyzed to show the effect of stress on the rate of creep and total creep. Creep properties of this laminate are also compared with creep properties of other plastics.

High-strength paper-base laminates are among the recent developments in the plastics field which are of considerable interest as potential aircraft materials. These laminates, made from special Mitscherlich paper impregnated with special resins and molded at low pressures, are currently finding a number of applications in which the load-carrying characteristics of the material are important. Three examples of such applications are aircraft wing tips, ammunition boxes, and fuselage sections. The tests reported in this paper were undertaken in order to provide needed information on the static strength and creep characteristics of this class of material.

The following tests were performed at a temperature of 77 F. and a relative humidity of 50 per cent: (1) static tension tests of specimens cut parallel and transverse to the grain of the paper; (2) compression tests of specimens cut with and across the grain; (3) torsion tests of specimens with the long axis cut parallel to the grain; (4) and creep tests under tension loading of specimens at eight different values of stress (specimens cut parallel to the grain). Values of compressive strength, tensile strength, yield strength, and modulus of elasticity were obtained from all of the static tests. All such tests were (as described below) conducted at nearly the same rate of tensile strain.

Several investigators have reported creep tests of both thermoplastic (**1, 3, 4, 6, 7, 8**)[2] and thermosetting types (**2, 5, 9, 10, 11**) of plastics. Most of the reported tests have covered only a very limited range of stress values and in many cases a limited duration—from 1 or 2 hr., in a few cases, to 1000 or 2000 hr. So far as the authors are aware, no creep tests of a Mitscherlich paper laminate have been reported.

---

[1] Assistant Professor and Instructor, respectively, of Theoretical and Applied Mechanics, College of Engineering, University of Illinois, Urbana, Ill.

[2] The boldface numbers in parentheses refer to the reports and papers appearing in the list of references appended to this paper, see p. 965.

Material:

The laminate for these tests was supplied by the Taylor Fiber Co. in December, 1942, and was made of high-strength Mitscherlich paper bonded under low pressure with a low-pressure type of phenolic resin. The Mitscherlich paper was made from wood pulp by the sulfite process. It was manufactured by Wisconsin Water Power and Manufacturing Co., and had the following characteristics:

Ream weight (480 sheets 24 by 36 in.)	30.8 lb.
Thickness	3.3 points
Mullen test	30.3 psi.
Gurley densometer test	20.4 sec.
Absorbency (5 min. in 16ths of an in.)	10.5
Tensile strength with the grain (1 in. wide)	32.3 psi.
Tensile strength across the grain (1 in. wide)	11.6 psi.

The Bakelite Corp. manufactured the single-stage resin (BV-16-238) and the catalyst (BK-16-253) used in setting the resin. As received the viscosity of the resin was 1389 centipoises at 80 F. For impregnating the paper, the resin was mixed with a specially denatured alcohol. After the paper was coated (impregnated) part of the volatile matter was driven off. The difference between the use of this resin in low pressure and high pressure laminating was that less volatile matter was driven off when the paper was to be laminated at low pressure.

The laminate was supplied in a sheet 48 by 48 in. by ½ in. thick and was designated by the manufacturer as TV2 grade XMLP. The molding cycle consisted of 30 min. heating at a platen temperature of 325 F. and a pressure of 230 psi. followed by 30 min. cooling. Grain direction of the paper was the same throughout the laminated sheet. The resin content of the laminate was 42 per cent and the volatile matter was 0.5 per cent, as determined by A.S.T.M. Standard Methods of Testing Sheet and Plate Materials Used in Electrical Insulation (D 229 – 43).[3]

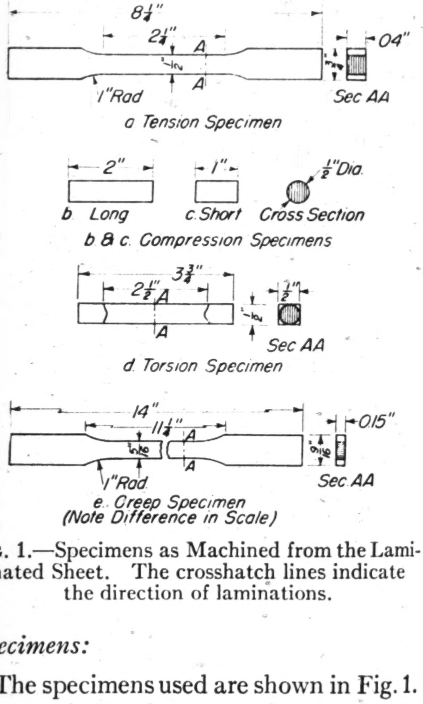


FIG. 1.—Specimens as Machined from the Laminated Sheet. The crosshatch lines indicate the direction of laminations.

Specimens:

The specimens used are shown in Fig. 1. The tension and compression specimens were machined from the sheet in each of two directions, one group with axes parallel and the other with axes perpendicular to the grain of the paper. The torsion and creep specimens were both cut with their axes parallel to the grain. All specimens were cut with their longitudinal axis parallel to the plane of the laminations. The tension specimens were machined on a shaper to the dimensions shown. Half of the tension specimens were then altered by filing the narrow section at the center so as to produce a gradual taper from $\frac{1}{2}$-in. width at the ends of the gage section to 0.01-in. undersize at the middle.

---

[3] 1943 Supplement to Book of A.S.T.M. Standards, Part III, p. 64.

The compression specimens were turned on a lathe to the two lengths shown in Fig. 1. The 2-in. specimen was used as shown in Fig. 5 to obtain stress-strain relationships. The short specimen was used to obtain ultimate strength values only. The torsion specimens were also machined by turning in a lathe. Considerable difficulty was encountered in turning this laminated material for the torsion and compression specimens because of its tendency to chip when cutting against the laminations. This difficulty was minimized by using high cutting speeds and frequent honing of the cutting tool.

The creep specimens were cut from the original sheet with a milling cutter in such a manner that the flat side of the specimen was perpendicular to the plane of the sheet. The reduced section and radii at the end were formed on a shaper.

All specimens were finished by sanding with No. 000 emery paper. All specimens were then placed in a room which was maintained at a constant temperature of 77 ± 1 F. and constant relative humidity of 50 ± 2 per cent, and were allowed to remain in this room for at least two weeks before the tests were started.

SHORT-TIME TENSION TESTS

Short-time tension tests were performed on specimens shown in Fig. 1(*a*). These specimens were tested in tension on an Olsen 10,000-lb. 4-screw machine. This was a beam-weighing machine equipped with a separate variable speed drive. The specimens were held in Templin wedge grips, *A*, Fig. 2, mounted in such a way as to provide an axial load on the specimens. The strain of the specimen was measured by means of a Moore-Hayes 2-in. gage length extensometer, *B*, Fig. 2. This instrument provided a multiplication such that one division on the dial indicated 0.0001 in. per inch strain in the specimen. In order to make it unnecessary for the specimen to support the weight of the extensometer, and in order to prevent damage to the instrument if the specimen should fracture while the extensometer was attached, the extensometer was suspended by means of the light coil spring *C* shown in Fig. 2.

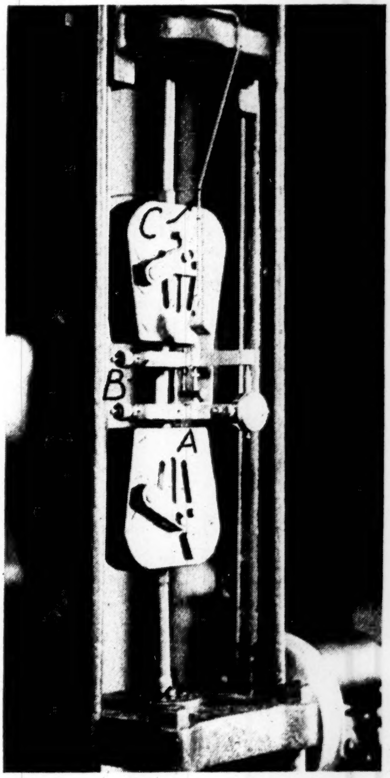


FIG. 2.—Apparatus for Tension Tests.

Tension tests were performed to determine the tensile properties of the material in two directions—parallel and perpendicular to the grain of the paper. Two sets of tension tests were run for each direction—one set in which the stress-strain characteristics were determined and the other set in which only the tensile strength was obtained. In the former group the gage section of the specimen was straight, and readings of load, deformation, and time were simultaneously obtained throughout the duration of the test. In the latter only the load at fracture was recorded. For this latter purpose the specimens with the width reduced at the middle to 0.01 in. less than the ends of the test section were used. This reduction in width was found necessary in order to cause the specimen to fail at the middle of the test section. Straight specimens failed at the shoulder as a result of the stress concentration at the fillet.

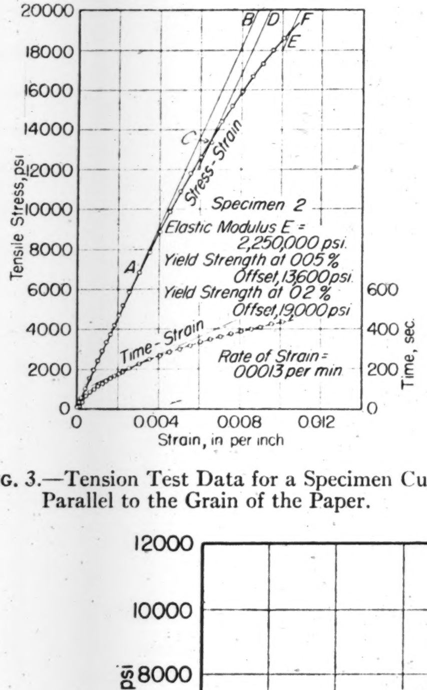


FIG. 3.—Tension Test Data for a Specimen Cut Parallel to the Grain of the Paper.

A preliminary test was made to determine the rate of testing speed required to produce a rate of tensile strain of about 0.0016 in. per inch per min. All succeeding tests were run at or near this rate of strain. This rate was selected in order to permit correlation between the results of these tests and tests performed by the authors on other materials (9). This rate of strain corresponds roughly to the rate of strain produced by testing machines operated at a head speed of 0.05 in. per min. However, it should be noted that different machines, and even different materials tested in the same machine at the same rate of cross-head motion, will not in general produce the same rate

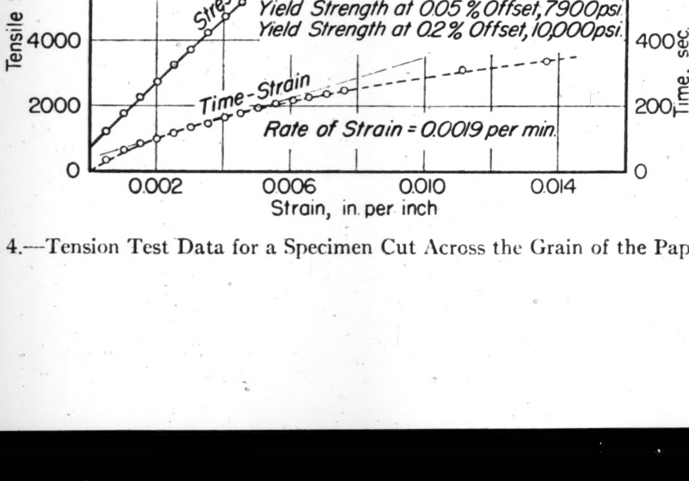


FIG. 4.—Tension Test Data for a Specimen Cut Across the Grain of the Paper.

of strain in the specimen. This is due to different relative stiffnesses of the machine, specimen, and auxiliary gripping apparatus.

The rate of strain was made uniform in these tests rather than the rate of increase of stress as used by some investigators, because the same rate of strain can be used without difficulty in testing materials which differ widely in modulus of elasticity, whereas if such materials are tested at the same rate of stressing, the required testing machine speeds become excessive for materials of low modulus, and the rate of strain becomes too high to follow with ordinary equipment.

Both the tension and the compression tests were performed outside of the air-conditioned laboratory. The temperature of the testing room was about 75 F. and the relative humidity was variable. In order to minimize the effect of differences in temperature and relative humidity, the specimens were placed in an insulated box while being transferred from the conditioned store room to the laboratory, and the tests were conducted within 5 to 10 min. after the specimen was removed from the insulated box. During the test, readings of load, deformation, and time were recorded up to a point within a few per cent of the load at which failure was expected. The extensometer was removed before failure.

From these data the stress and strain were computed. Then diagrams of stress *versus* strain, and time *versus* strain were plotted. An example of such a plot for a tension test of a specimen whose axis was parallel to the grain of the paper is shown in Fig. 3, and a similar plot for a tension test of a specimen with axis transverse to the grain is shown in Fig. 4. The modulus of elasticity was determined in each case from the slope of the initial part of the stress-strain curve. The yield strengths[4] at 0.05 and 0.2 per cent offset were determined by noting the values of stress at points *C* and *E* (Fig. 3) respectively, at which a line *CD* or *EF*

TABLE I.—TENSION TESTS.

Specimen	Modulus of Elasticity, *E*, psi.	Yield Strength, psi.		Tensile Strength, psi.	Rate of Strain, per min.	Direction of Load
		0.05 per cent offset	0.2 per cent offset			
No. 2	2 250 000	13 600	19 000	20 400	0.0013	Parallel to grain of paper
No. 4	2 270 000	10 300	16 600	19 400	0.00051	
No. 5	2 190 000	12 100	18 400	20 300	0.0013	
Average	2 240 000	12 000	18 000	20 000	....	
No. 1	....	....	....	19 500	0.0013	
No. 3	....	....	....	20 200	0.0013	
No. 6	....	....	....	19 200	0.0013	
Average	....	....	....	19 600	....	
No. 1X	990 000	7 900	10 000	11 800	0.0019	Perpendicular grain of paper
No. 2X	1 110 000	7 100	9 400	11 700	0.0012	
No. 3X	1 140 000	7 500	....	12 100	0.0013	
Average	1 080 000	7 500	9 700	11 900	....	
No. 4X	....	....	....	11 700	0.0013	
No. 5X	....	....	....	11 600	0.0013	
No. 6X	....	....	....	12 000	0.0013	
Average	....	....	....	11 800	....	

---

[4] See A.S.T.M. Standard Definitions of Terms Relating to Methods of Testing (E 6 – 36), 1942 Book of A.S.T.M. Standards, Part III, p. 849.

drawn parallel to the initial tangent line *AB*, and offset from the tangent line by 0.05 and 0.2 per cent, crossed the stress-strain line.

The rate of strain was determined from a time-strain curve by measuring the reciprocal of the slope of this curve in the region just below the value of strain above which the stress was no longer proportional to strain, point *A*, Fig. 3. The tangent line used is shown in each figure.

Results of the tension tests are shown in Table I. The average value of the modulus of elasticity parallel to the grain of the paper was found to be 2,240,000 psi. No significant difference was observed between the strengths determined with the two different shapes of specimens. The tensile strength of the straight specimens averaged 20,000 psi. and the strength as obtained from the tapered specimens averaged 19,600 psi. The average yield strength at 0.05 per cent offset was 12,000 psi., and at 0.2 per cent offset the average yield strength was 18,000 psi. Some difference existed between the rates of strain in the specimens used for these tests, however, no detectable difference in properties could be attributed to the variation of the strain rate existing between the tests.

The result of the tests of specimens cut crosswise to the grain of the paper showed that the modulus of elasticity in this direction was 48 per cent of the modulus in the direction of the grain, the ultimate strength transverse was 60 per cent of the tensile strength with the grain, and the yield strengths at 0.05 and 0.2 per cent offset were 63 and 54 per cent, respectively, of the values obtained from tests parallel to the paper grain.

Short-Time Compression Tests:

Short-time compression tests were performed to determine the compressive properties in the same two directions as the tension tests, that is, parallel, and perpendicular to the grain of the paper. Compression specimens were tested in the same machine as the tension specimens, and under the same temperature and humidity conditions. In order to minimize the effect of possible eccentric loading the specimens were tested by using a compression tool, *A*, shown in Fig. 5. A compressometer, *B*, of one to one ratio having a 0.0001 in. Last Word dial and 1-in. gage length was used to

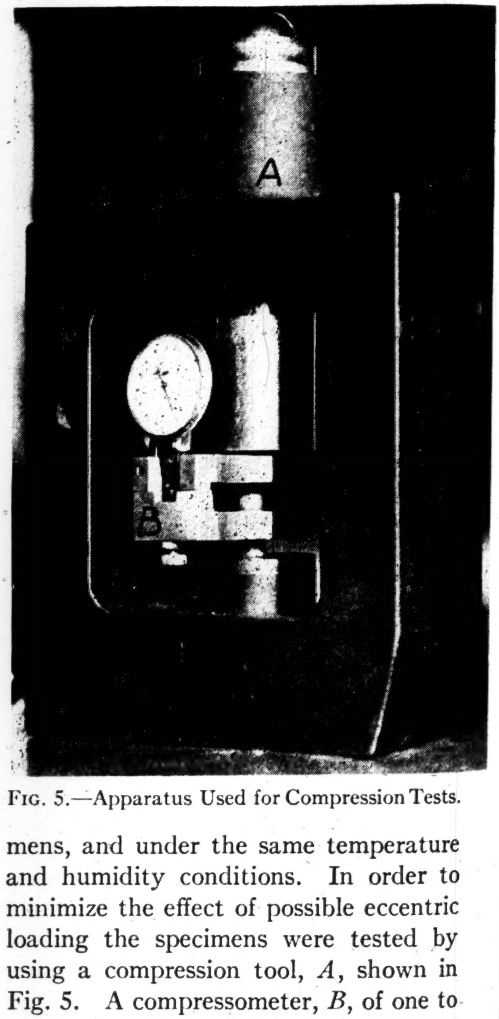


FIG. 5.—Apparatus Used for Compression Tests.

determine the strain. As in the case of the tension tests, the instrument was supported on a light coil spring.

Two different shapes of specimens were required, one to determine stress-strain relations and another the compressive strengths, Fig. 1. The 2-in. specimen ($l/r = 16$)[5] was used with the 1-in. gage length compressometer to determine the

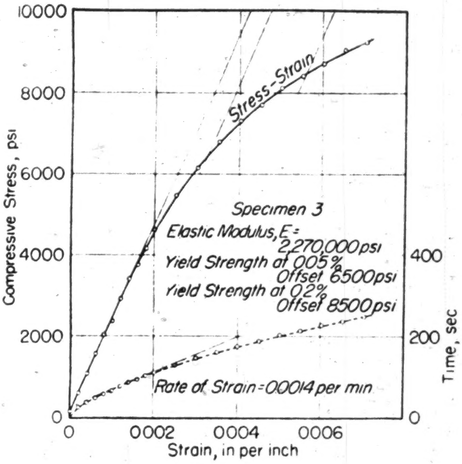


FIG. 6.—Compression Test Data for a Specimen Cut Parallel to the Grain of the Paper.

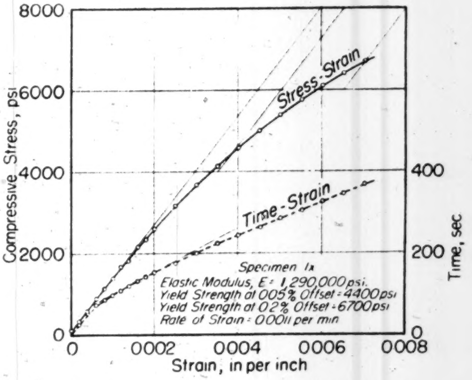


FIG. 7.—Compression Test Data for a Specimen Cut Across the Grain of the Paper.

---

[5] l/r is the ratio of the length of the specimen to the radius of gyration of the cross-section of the specimen.

TABLE II.—COMPRESSION TESTS.

Specimen	Modulus of Elasticity, E, psi.	Yield Strength, psi.		Compressive Strength, psi.	Rate of Strain, per min.	Direction of Load
		0.05 per cent offset	0.2 per cent offset			
2 in. long						Parallel to grain of paper
No. 1	2 370 000	7 300	9 200	19 600	0.0031	
No. 2	2 360 000	6 600	8 600	....	0.0015	
No. 3	2 270 000	6 500	8 500	....	0.0014	
No. 5	2 220 000	6 400	8 400	....	0.0014	
No. 6	2 220 000	7 100	8 800	....	0.0015	
Average	2 290 000	6 800	8 700	....	....	
1 in. long						
No. 1′	....	....	....	17 800	0.0022	
No. 2′	....	....	....	17 500	0.0022	
No. 3′	....	....	....	17 900	0.0022	
No. 4′	....	....	....	17 600	0.0022	
Average	....	....	....	17 700	....	
2 in. long						Perpendicular to grain of paper
No. 1X	1 290 000	4 400	6 700	....	0.0011	
No. 2X	1 280 000	4 800	7 000	16 200	0.0015	
No. 3X	1 250 000	4 800	7 200	15 500	0.0015	
No. 5X	1 290 000	4 700	7 000	15 000	0.0015	
No. 6X	1 340 000	4 500	6 800	15 200	0.0015	
Average	1 290 000	4 600	6 900	15 500	....	
1 in. long						
No. 1X′	....	....	....	14 400	0.0015	
No. 2X′	....	....	....	14 300	0.0015	
No. 3X′	....	....	....	13 800	0.0015	
No. 4X′	....	....	....	13 800	0.0015	
No. 5X′	....	....	....	15 500	0.0015	
Average	....	....	....	14 400	....	

stress-strain relations. The 1-in. specimen ($l/r = 8$) was used to determine the compressive strength of the material.

During the compression tests of the 2-in. specimens, readings of load, deformation, and time were recorded. From these data the stress and strain were computed, and stress-strain and time-strain curves were plotted. Figure 6 shows these two curves for a compression test of a specimen cut parallel to the grain of the paper and Fig. 7 shows the same two curves for a specimen cut crosswise of the grain. The modulus of elasticity, yield strength at 0.05 and 0.2 per cent offset, and the rate of strain were determined from these curves in the same manner as that described for the tension tests.

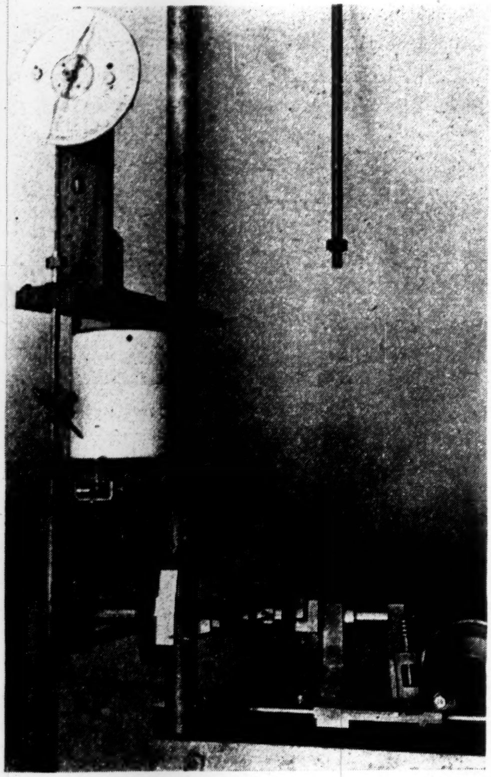


FIG. 8.—Torsion Testing Machine.

Results of the compression tests are shown in Table II. The average value of the modulus of elasticity with the grain of the paper was 2,290,000 psi. The compressive strength, as measured from the short specimens, was 17,700 psi. One of the long specimens was tested to failure at 19,600 psi. No satisfactory explanation has been found for this higher strength—lower strength was expected because of column action. The small variation in temperature which may have existed was not enough to produce such a large change, nor was it likely that the difference in rate of strain would produce as much effect as noted. The rate of strain in the 1-in. specimens was determined by comparing the loading rate with the loading rate in a 2-in. specimen.

The result of tests of specimens cut perpendicular to the grain of the paper show that the modulus of elasticity was 56 per cent of that parallel to the grain, the compressive strength across the grain was 81 per cent of the strength with the grain, and the yield strengths at 0.05 and 0.2 per cent offset were 68 per cent and 79 per cent, respectively, of the lengthwise test values.

Short-Time Torsion Tests:

The special torsion testing machine used for these tests is shown in Fig. 8. The machine was constructed as an attachment for a low-capacity tension testing machine. The pendulum weighing system of the tension testing machine was used as the torque measuring device for the torsion machine. This was accomplished by attaching to the tension machine a twisting head, *A*, Fig. 8, driven by a double worm drive. A special chuck, *B*, was attached to the shaft of this twisting head and another chuck, *C*, to the axis of the pendulum, *D*. These chucks were designed to apply a torque to the specimen with little danger of bending the specimen at the same time. This action was further assisted by mounting the specimen on centers and applying the torque as a couple by means of adjustable screws.

The gage used for measuring the shearing strain is shown in Fig. 9. It was designed to accommodate materials whose ultimate shearing strain was relatively small and also materials which might twist two or three revolutions in a length of 2 in. The instrument consisted of two rings, *A*, Fig. 9, which were slipped over the specimen and fastened to it by three adjusting screws in each ring. A gage length of 2 in. was obtained by use of a removable spacer, *B*. To one of the rings was fastened a circular scale, *C*, for measuring large angles of twist. Two 10-in. arms, *D*, fastened to the same ring carried scales on the ends which were used to measure small shearing strain. Adjustable pointers, *E*, were attached to the other ring in such a way as to indicate the readings on their respective scales.

Torsion tests differ from tension and compression tests in two important respects. They differ in the state of stress developed and in the stress gradient. The state of stress may be defined in terms of the ratio $\frac{\sigma_{max}}{\tau_{max}}$, that is, the ratio of the maximum tensile stress to the maximum shearing stress at a point in a stressed member. In a tension member this ratio is 2, while in a torsion member it is 1. Thus some materials may behave very differently in the two types of tests. The stress gradient is a measure of the distribution of stress over the cross-section of a member. It has a value of 0 in a tension member, but can never be 0 in a torsion member. The magnitude of the stress gradient in a torsion member depends on the stress and the diameter of the member. The measured strength of a material may be influenced by the stress gradient so as to produce different results in the tension test and in the torsion test.

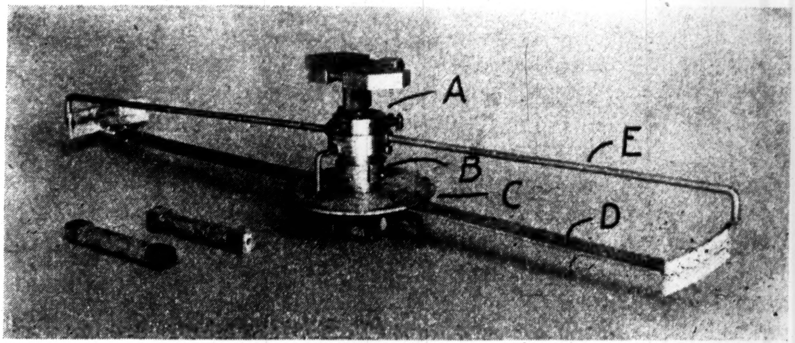


FIG. 9.—Detrusion Gage Used for Measuring the Angle of Twist in Torsion.

Laminated materials such as the Mitscherlich paper plastic described herein are anisotropic; that is, their properties are not the same in all directions. In the tension and compression specimens with axis parallel to the laminations the maximum tensile stress is in the same direction throughout the test specimen. However, in a torsion specimen with axis parallel to the laminations both the tension and shearing stresses have different directions (relative to the axes of the laminated sheet) at different points around the circumference of the specimen. Thus the equations of stress and strain for torsion of an isotropic member cannot be expected to indicate accurately the stress or strain in this anisotropic material. Nevertheless, the following equations developed for isotropic materials were used here to give nominal values of shearing stress and strain as a basis for comparison. The equation for shearing stress in a circular member of an isotropic material subjected to torsion is $\tau = \frac{Tc}{J}$, and the corresponding equation for shearing strain is $\gamma = \frac{c\theta}{l}$.

In the case of a laminated material, the torsion test may serve as an indication of the relative shearing strength of the bond between laminations. That is, in a laminated material failure is likely to take place by shearing parallel with the laminations.

Short-time torsion tests were performed on specimens, Fig. 1, *d*, cut from the sheet with their longitudinal axes parallel to the grain. In order to provide comparable conditions for tension, compression and torsion tests, it was desirable to have equal rates of strain for all tests. In order to accomplish this, the rate of tensile strain was kept as nearly the same as possible in all three types of tests. In a circular torsion member the maximum tensile stress occurring at a point acts on a plane at 45 deg. to the plane of the maximum shearing stress and is equal to the maximum shearing stress. Hence, the shearing rate of strain can be computed from the tensile rate of strain by the relation $\frac{d\gamma}{dt} = \frac{E}{G} \cdot \frac{d\epsilon}{dt}$, where $\frac{d\gamma}{dt}$ is the shearing rate of strain, $\frac{d\epsilon}{dt}$ is the tensile rate of strain, and $\frac{E}{G}$ is the ratio of tensile modulus of elasticity to shearing modulus. This equation, also, is inexact owing to the anisotropic character of the material. The required rate of strain was determined from the value of *G* determined in a preliminary test. The resulting shearing rate of strain required was 0.012 per min. which was rather fast owing to the low value of *G*. Thus it was possible to obtain only relatively few test points in the elastic range at this rate of testing.

During the torsion test simultaneous readings of torque, angle of twist, and time were recorded. The nominal shearing stress at the surface of the cylindrical specimen and the nominal shearing strain were computed from the relationship given above.

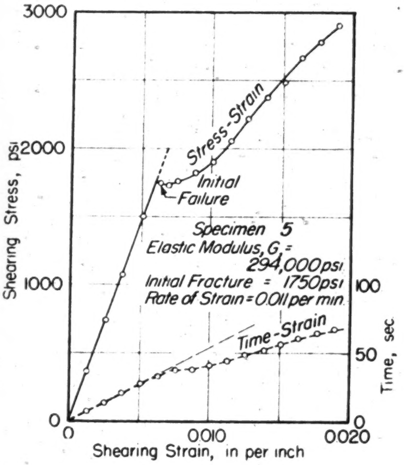


FIG. 10.—Torsion Test Data for a Specimen Cut Parallel to the Grain of the Paper.

Curves of shearing stress *versus* shearing strain and time *versus* shearing strain were then plotted as in Fig. 10. The shearing modulus of elasticity, *G*, and rate of shearing strain were determined as in the case of tension tests. The torsion tests differed from the tension and compression tests in regard to

TABLE III.—TORSION TESTS.
Axis of Specimen Parallel to Paper Grain.

Specimen	Shearing Modulus of Elasticity, *G*, psi.	Stress at Initial Fracture, psi.	Modulus of Rupture, psi.	Rate of Strain, per min.
No. 2	285 000	2 240	3 000	0.0016
No. 3	295 000	2 550	3 000	0.015
No. 4	294 000	2 540	3 120	0.0064
No. 5	294 000	1 750	2 900	0.011
No. 6	296 000	1 890	3 050	0.012
No. 7	291 000	2 370	3 170	0.011
No. 8	272 000	1 960	2 580	0.013
No. 9	292 000	2 140	2 400	0.013
No. 10	282 000	2 290	2 480	0.013
No. 11	292 000	2 260	2 460	0.013
	289 000	2 200	2 820	

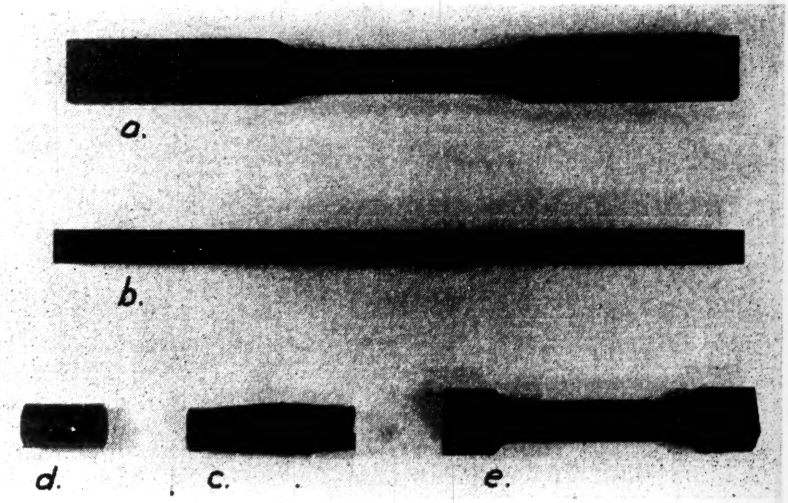


FIG. 11.—Fractured Specimens.

(*a*) Tension specimen viewed flatwise.
(*b*) Tension specimen viewed edgewise.
(*c*) Long compression specimen.
(*d*) Short compression specimen.
(*e*) Torsion specimen.

shape of the stress-strain curve. In the torsion tests, the stress increased as a linear function of strain up to a certain point at which initial failure or structural damage took place, that is, at which large increase in strain took place at nearly constant stress. The torque was then increased more gradually to a maximum value at which more general damage or failure took place by splitting parallel to the laminations. For the torsion test, the value of stress at which the initial failure took place was reported, rather than a yield strength corresponding to a specified offset.

The results of torsion tests are tabulated in Table III. The average value of the modulus of elasticity in shear, as determined from equations for isotropic material, was 0.289×10^6 psi. The ultimate shearing strength (modulus of rupture in torsion) was 2820 psi., and the average shearing stress at the initial failure of the glue bond was 2200 psi.

Mode of Failure:

Representative fractured specimens from the short-time tension, compression, and torsion tests are shown in Fig. 11. Two views of failed tension specimens, *a* and *b*, are shown. A tendency to shatter and split along the laminations was noticed in many specimens. Characteristic failures of both 2-in. and 1-in. compression specimens are shown in Fig. 11 *c* and *d*. The long specimens tended to fail by splitting parallel to the load, then buckling. The short specimens failed diagonally across the laminations on planes of maximum shear. A failed torsion specimen is shown in Fig. 11 *e*. This failure resulted from splitting along laminations with occasionally a segment breaking completely off.

In certain parts of the sheet tested there was evidence of initial delamination near the center indicating imperfect bonding. Because of this fact care was exercised in preparing specimens to avoid as much as possible regions in which imperfect bonding was evident.

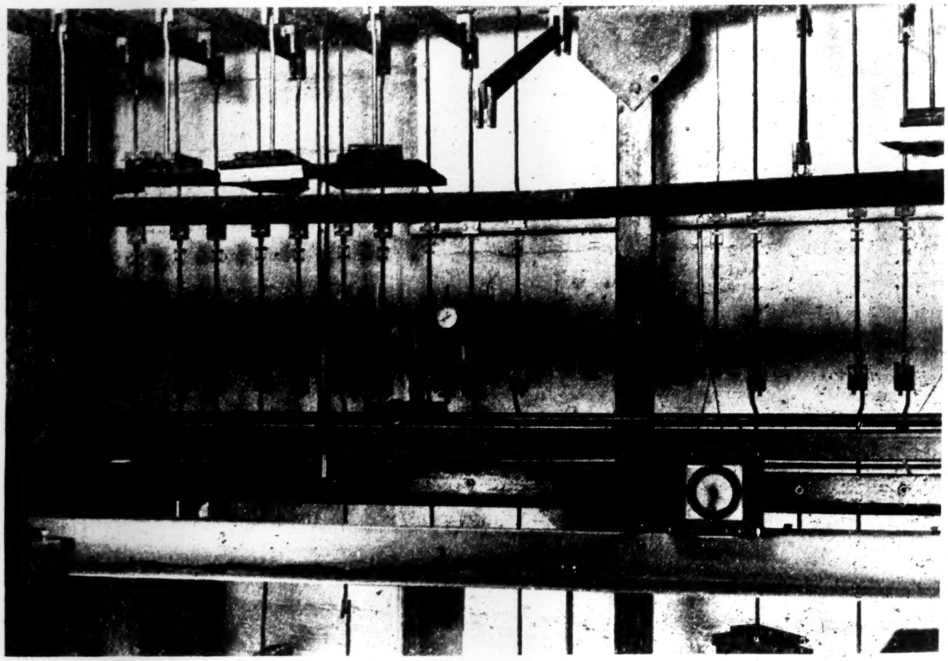


FIG. 12.—Creep Rack.

Comparison of Static Tests:

The results of tests of specimens cut parallel to the grain (Tables I, II, III) showed that the modulus of elasticity in compression was slightly higher than the modulus in tension, whereas the modulus of elasticity in shear as measured from the torsion tests was about $\frac{1}{8}$ the tension modulus. The ultimate strength in compression was about 10 per cent less than that in tension, but the yield strength at 0.2 per cent offset in compression was only about $\frac{1}{2}$ that in tension. The modulus of rupture in torsion was about $\frac{1}{4}$ the ultimate strength in tension, and the initial (delaminating) fracture in torsion was about $\frac{1}{8}$ the yield strength in tension at 0.2 per cent offset.

LONG-TIME TENSION CREEP TESTS

The equipment used for conducting the creep tests consisted of a steel rack from which 22 specimens could be suspended; calibrated weights and levers used for loading the specimens in tension; calibrated extensometers and a traveling microscope used for measuring the strain indicated by the extensometer; and a clock equipped with a counter to record the elapsed time in hours. Figure 12 shows the creep rack with loading levers, specimens, extensometers, and auxiliary equipment. Figure 13 shows a specimen with strain measuring equipment in place. In this figure specimen *A* was subjected to an axial tensile load through rod *B*. The specimen was held by grips *C* which contained a hook and eye type of swivel joint. This joint was provided in order to minimize the possibility of eccentric loading. The extensometer used for measuring the creep consisted of a lever type instrument with a traveling microscope, *D*, Fig. 13, for measuring the displacement between reference marks on the end of the lever, *E*, and a stationary arm, *F*. The lever ratio was 10 to 1. One end of the lever was forked and fastened by pivots to the lower clamp attached to the specimen. The axis of this pivot passed through the centroid of the cross-section of the specimen (the pin itself did not go through the specimen). Thus the strain measured by this instrument was the average strain in the specimen, and it was not necessary to average the result of two or more instruments fastened to different sides of the specimen. The fulcrum of the lever was pivoted to a rod, the other end of which was fastened to the upper clamp on the specimen. A spring clip *G*, Fig. 13, was

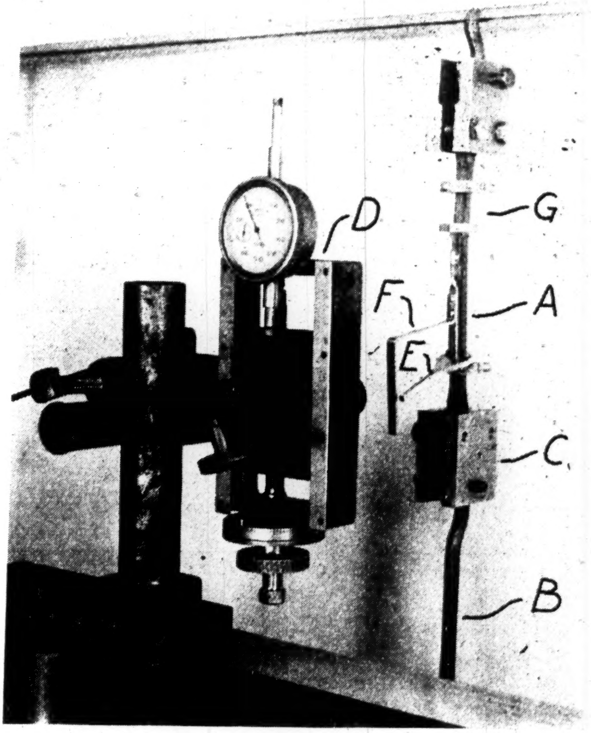


Fig. 13.—Creep Measuring Apparatus.

used to attach this rod to the upper clamp so that the extensometer could be left on the specimen during fracture if necessary without damage to the instrument.

Each instrument was calibrated against a micrometer screw before use. Flat clamps were used to attach the extensometer to the specimen instead of pointed screws because creep of the material might cause screws to sink into the specimen, thus causing early fracture. The distance between the centers of the flat clamps was considered to be the gage length of the extensometer. As used in these tests, this gage length was 10 in. although in Fig. 13 the extensometer is set for 4 in. A track was provided for the microscope so that it could be moved from specimen to specimen quickly.

Eight creep specimens, Fig. 1 *e*, were tested simultaneously under a constant tension load at values of stress ranging from 0 to 9000 psi. These tests were conducted in a room maintained at a constant temperature of 77 F. and a constant relative humidity of 50 per cent for the entire time of the test which was 7000 hr., or about 10 months. One specimen was tested at 0 stress in order to determine the magnitude of the shrinkage which might occur due to gradual change in moisture content or other aging phenomena. All tests were started at approximately the same time, and all were started by applying loads quickly but very gently to the specimens. Before applying the load, the initial extensometer readings were obtained with the traveling microscope. Then the loads were applied, the time was recorded, and the extensometer was immediately read again. On the basis of the difference between these two sets of readings, the elastic strain was computed. Readings of strain and time were thereafter taken at intervals varying from two hours to seven days.

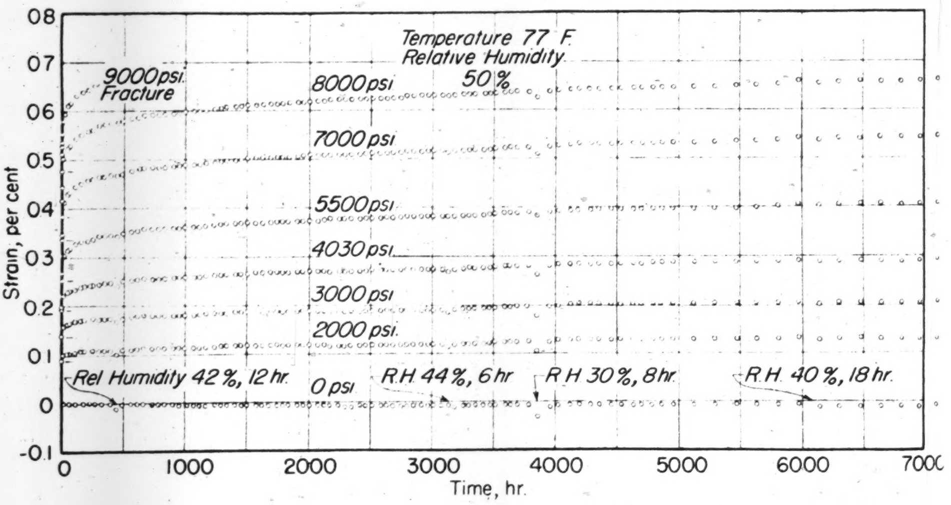


FIG. 14.—Creep *versus* Time for Tension Creep Tests at Constant Load.

The results of these tests were plotted as shown in Fig. 14. It was observed that the tests started with a rather rapid rate of creep which decreased as time progressed. The lowest curve plotted in Fig. 14 is from the data from a specimen which carried no load, that is, 0 stress. This specimen was observed to shrink slightly during the first half of the test, possibly as a result of continuing reduction of the moisture content of the specimen. The effect of short interruptions in humidity control is evident in all curves shown in Fig. 14. A decrease in relative humidity was observed to result in a rather marked decrease in length of all specimens, that is, a shrinkage, the amount of which was approximately the same for all specimens, regardless of stress.

The specimen which was loaded to 9000 psi. fractured after about 300 hr. The fracture, which occurred at the shoulder of the specimen, resulted primarily from delamination at that point. Thus, the actual stress which caused failure is not accurately known. The plotted point representing "elastic" strain in each specimen is indicated by a short horizontal line at 0 time.

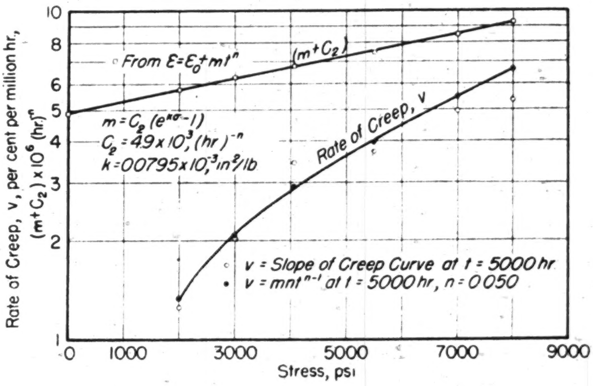


FIG. 15.—The Effect of Stress on the Rate of Creep and $(m + C_2)$.

The Effect of Stress on the Rate of Creep:

The rate of creep did not remain constant throughout the time of testing, but decreased rapidly at first and then more gradually. In order to evaluate the effect of stress on the different rates of creep, it was therefore necessary to determine the rate of creep at any definite time. The rate was determined for a time of 5000 hr. by measuring the slope of the creep-time curve at 5000 hr. for each stress shown in Fig. 14. This rate of creep was then plotted against the stress on semi-logarithmic coordinates and is shown as the open circles in Fig. 15.

It has been found that the data shown in Fig. 14 can be represented by an equation (12) as follows:

$$\epsilon = mt^n \text{............} 1$$

where ϵ is the total strain and t is the time. The quantity m depends upon the stress, whereas n is independent of the magnitude of the stress and depends upon material and, possibly, temperature. Since the rate of creep is defined as $\frac{\partial \epsilon}{\partial t}$, it is possible to compute the rate of creep by taking the time derivative of Eq. 1, from which:

$$v = \frac{\partial \epsilon}{\partial t} = m\,n\,t^{n-1} \text{........} 2$$

Thus the rate of creep, v, can be computed by substituting the values of m and n, determined in a manner described in another paper (12), and the value of the time, 5000 hr., into Eq. 2.

The values of rate of creep computed in this manner are plotted in Fig. 15 as filled circles. This method of determining the rate of creep for a particular time is more accurate than the slope method, and may therefore be expected to give more consistent results, as is shown in Fig. 15.

It has also been found that the factor m can be expressed as a function of stress in the following form (as shown in reference **11**):

$$m = C_2e^{k\sigma} - C_2 = C_2(e^{k\sigma} - 1) \quad \ldots 3$$

in which σ is the tension stress, C_2 and k are constants. As shown in reference **11** the fact that Eq. 3 accurately describes the relation between the factor m and stress σ is demonstrated by the fact that $(m + C_2)$, when plotted semi-logarithmically against stress, yields a straight line as shown by the square points plotted in Fig. 15. Thus, the rate of creep can be expressed as a function of stress by substituting Eq. 3 in Eq. 2 with the result:

$$v = C_2(e^{k\sigma} - 1)nt^{n-1} \quad \ldots\ldots 4$$

The Effect of Stress on the Amount of Creep:

In order to evaluate the effect of stress on the magnitude of creep, the amount of total creep at a given time was plotted against the stress for each of the eight values of stress and is shown in Fig. 16. The elastic extension is shown as the lower curve in Fig. 16, and values of total creep at 100 hr., 1000 hr., and 6000 hr. are also shown. It was observed that most of the continuing deformation occurred within the first 100 hr., and also that the increase of deformation after the first 100 hr. to 6000 hr. was less than the initial, or elastic, deformation. The modulus of elasticity as determined from the reciprocal of the slope of the elastic curve shown in Fig. 16 was found to be 2,200,000 psi., as compared to 2,240,000 psi. determined from the short-time tension test.

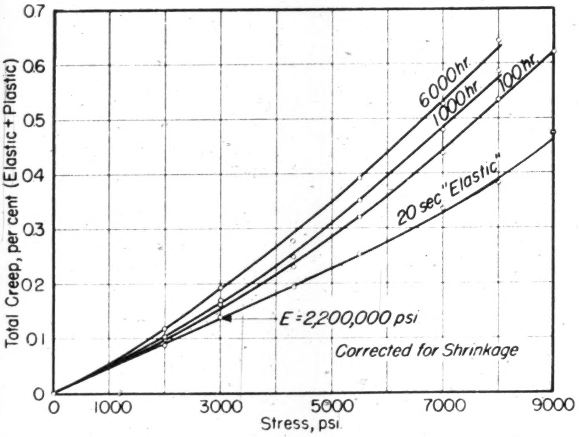


FIG. 16.—The Effect of Stress on the Total Creep for Four Different Time Intervals.

Comparison of Creep Properties with other Materials:

A comparison of the creep properties of this laminate with other thermosetting plastics for which test data were available showed that the total creep of all molded phenolic plastics reported (**9**) was 1.5 to 3 times that for the Mitscherlich paper at a stress of 2000 psi., a time of 1000 hr., a temperature of 77 F., and a relative humidity of 50 per cent.

The materials studied in the references cited included phenolics filled with cord, rag, wood flour, asbestos, mica, and pure resin. The Mitscherlich laminate also showed less total creep than any laminates for which creep data were available to the authors (**11**). These laminates were phenolic laminates grades C, L, and XX. The grade C laminate had 2 to 3 times (depending on the stress) greater total creep at 1000 hr. than did the Mitscherlich paper. Grades L and XX had about 60 per cent and 10 per cent greater creep, respectively, at 8000 psi. and 1000 hr. than did the Mitscherlich paper. The grade XX laminate was tested at a relative humidity of 43 per cent which would tend to decrease the amount of creep; however, the fact that the modulus of elasticity of the grade XX was about 25 per cent less than the modulus of the Mitscherlich paper would indicate that the increase in strain under the constant stress was about the same for the two materials.

SUMMARY AND CONCLUSIONS

1. At a tensile rate of strain of 0.0016 per min., the modulus of elasticity in tension was 2,240,000 psi. parallel to the grain of the paper and 1,080,000 psi. across the grain.
2. The elastic modulus in compression was about the same as the corresponding values in tension.
3. However, the shearing modulus of elasticity as determined from a torsion test was 289,000 psi.
4. The ultimate strengths were as follows: tension, 19,600 psi. parallel to the grain and 11,800 psi. across the grain; compression, 17,700 psi. parallel and 14,400 psi. across; shearing (modulus of rupture in torsion), 2820 psi. as determined from a specimen cut parallel to the grain of the paper.
5. The increase in strain due to creep was 0.26 per cent after 6000 hr. at a tension stress of 8000 psi. This increase in strain was equal to about 70 per cent of the "elastic" strain at the same stress.
6. Creep data from 8 specimens at different values of stress have been analyzed, with reference to another similar discussion, to show the effect of stress on creep and the rate of creep. The rate of creep was found to decrease with time, but for any given time the rate of creep, v, was shown to be related to stress σ by an exponential equation of the form:

$$v = C_2(e^{k\sigma} - 1)nt^{n-1}$$

where t is the time, and C_2, k, and n are constants.

Acknowledgment:

The project reported upon in this paper was part of the work of the Engineering Experiment Station of the University of Illinois, Dean M. L. Enger, director, in the Department of Theoretical and Applied Mechanics, of which F. B. Seely is head. The authors wish to express their gratitude to F. B. Seely for making it possible to carry on this work and for assistance in preparing the manuscript. They are also indebted to C. D. Kacalieff and W. M. Owen for assistance in conducting the short-time tests.

The authors take pleasure in acknowledging the generous cooperation of G. J. Muller of Taylor Fiber Co. who supplied the material and the information regarding its manufacture.

REFERENCES

(1) W. F. Bartoe, "Service Temperature Flow Characteristics of Thermoplastics," *Mechanical Engineering*, Vol. 61, No. 12, December, 1939, p. 892.

(2) H. Leaderman, "Creep, Elastic Hysteresis, and Damping in Bakelite under Torsion," *Journal of Applied Mechanics*, Vol. 6, No. 2, June, 1939, p. A-79.

(3) C. H. Penning and L. W. A. Meyer, "Cold Flow of Thermoplastic Materials," *Modern Plastics*, Vol. 17, No. 3, November, 1939, p. 91.

(4) S. S. Kistler, "The Thermoplastic Behavior of Linear and Three Dimensional Polymers," *Journal of Applied Physics*, Vol. 11, p. 769 (1940).

(5) H. Perkuhn, "The Creep of Laminated Synthetic Resin Plastics," *Luftfahrtforschung*, Vol. 18, No. 1, Feb., 1941, p. 32; National Advisory Committee for Aeronautics Technical Memo. No. 995.

(6) J. Delmonte and W. Dewar, "Factors Influencing Creep and Cold Flow of Plastics," ASTM BULLETIN, No. 112, October, 1941, p. 35.

(7) W. N. Findley, "Mechanical Tests of Cellulose Acetate—Part II, Creep," *Proceedings*, Am. Soc. Testing Mats., Vol. 42, p. 914 (1942).

(8) R. Burns, "Deformation Under Load of Rigid Plastics," *Proceedings*, Am. Soc. Testing Mats., Vol. 43, p. 1194 (1943).

(9) D. Telfair, T. S. Carswell, and H. K. Nason, "Creep Properties of Molded Phenolic Plastics," *Modern Plastics*, Vol. 21, No. 6, February 1944, p. 137.

(10) B. Chasman, "Creep and Time-Fracture Strength of Plastics Under Tensile Stresses," *Modern Plastics*, Vol. 21, No. 6, p. 145 (1944).

(11) W. N. Findley, "Creep Characteristics of Plastics," 1944 Symposium on Plastics, Am. Soc. Testing Mats., p. 118 (1944). (Symposium issued as separate publication.)

DISCUSSION

MESSRS. D. TELFAIR[1] AND H. K. NASON[1] (*presented in written form*).—Messrs. Findley and Worley are to be complimented on another careful investigation of the type for which their laboratory has become noted. Their fine work is providing us with valuable information on the mechanical properties of plastic materials and will greatly facilitate the understanding of plastics as engineering materials.

The authors perhaps have been unfortunate in the choice of material for their investigation since their data show this material to be of rather poor quality. The mode of failure which they observed, as well as some of the strength values, indicate that the high-grade paper laminae were poorly bonded. Whether this defect is due to the resin employed or to the method of handling it cannot be determined from the data at hand. It is hoped that similar investigations will be made of high-strength plastic laminates whose quality is more nearly that of commercial materials used for stressed parts.

The analysis of the creep data introduced by the authors is very interesting indeed. It is worth while to note that the equation $\epsilon = mt^n$, which was mentioned by Boyd in his discussion of Marin's[2] paper presented before the Society in 1937 applies to plastic materials as well as to metals at elevated temperatures.

One point concerning the use of the equation $\epsilon = \epsilon_0 + mt^n$ puzzles us. If the exponent, n, is actually independent of stress, as stated, then log $(\epsilon - \epsilon_0)$ would still increase linearly with time for zero stress. Hence, the expression cannot be correct for this limiting case.

The use of the torsion test as a criterion of bonding strength is worth noting. In general, the value of torsion tests in the study of plastic materials has been neglected and further study along these lines would be well worth while.

Strictly speaking, the state of stress requires 3 parameters for its definition. Usually, the three principal stresses are taken; thus the ratio $\sigma_{\max.}/\tau_{\max.}$ does not completely define it.

It is hoped that Mr. Findley and his colleagues at the University of Illinois will continue their interest in plastic materials and that we may expect many more of their valuable contributions in the years to come.

MR. R. T. SCHWARTZ[3] (*by letter.*)—With reference to the paper entitled, "Short-Time Static Tests and Creep Tests of a Paper Laminated Plastic" by Findley and Worley, attention is called to the fact that the properties of the material tested do not meet the minimum required values of Army Air Forces Specification No. 12036, Phenolic Sheet; Laminated High Strength Paper Base, and therefore should not be interpreted as representative of this type of material used in Army aircraft. A comparison of minimum values is given in the accompanying Table I.

---

[1] In Charge of Physical Testing and Assistant Director of Research, respectively, Plastics Div., Monsanto Chemical Co., Springfield, Mass.

[2] John Boyd, discussion of paper by Joseph Marin on "A Comparison of the Methods Used for Interpreting Creep Test Data," *Proceedings*, Am. Soc. Testing Mats., Vol. 37, Part II, p. 265 (1937).

[3] Materials Engineer, Materials Lab., Engineering Div., Army Air Forces, Wright Field, Dayton, Ohio.

It is also desired to point out that no aircraft wing tips or fuselage sections are being produced from this type of material so far as is known, although such items have been made experimentally. Turret parts, ammunition boxes, and glider flooring using the specification type material are in production for Army aircraft, however.

TABLE I.

	Minimum Values, AAF Specification 12036, Type II, Parallel Laminated	Minimum Values, Materials Tested by Findley and Worley
Tensile strength, psi.		
lengthwise	28 000	19 200
crosswise	18 000	11 600
Tensile yield strength, 0.2 per cent offset, psi.		
lengthwise	22 000	16 600
crosswise	12 000	9 400
Modulus of elasticity, psi.		
lengthwise	2 600 000	2 190 000
crosswise	1 400 000	990 000
Compressive strength, psi. (2 in. length specimen, ½ in. thick)		
lengthwise	19 000	17 600
crosswise	17 000	15 000

MESSRS. W. N. FINDLEY AND W. J. WORLEY[4] (*authors' closure, by letter*).—The observation of the discussers concerning the quality of the material which the authors tested is correct. However, it perhaps should be mentioned that the tests reported have been in progress for a long time—the material was molded in December, 1942. At that time, Mitscherlich laminates were quite new, so that improvement in properties was to be expected, and it is natural that as long as science continues to produce improved materials, an improved material may be on the market before the results of long-time tests of earlier materials become available. It would be unfortunate, however, if one should conclude from this fact that there is no use making long-time tests, for without them, it would be impossible to predict the behavior of either the old or the new material.

The authors believe that Messrs. Telfair and Nason are mistaken in their interpretation of the equation $\epsilon = \epsilon_0 + mt^n$ in the region of zero stress. Since m is a function of stress σ, and has the value zero when σ is zero (Eq. 3), then for a stress of zero, $\epsilon = \epsilon_0 =$ a constant independent of time. This conclusion is true, regardless of whether n is or is not independent of stress, and is in agreement with experience and with the definition of creep. Thus, for zero stress, log $(\epsilon - \epsilon_0)$ is the log of zero which is negative and *indefinitely* large. The interpretation of the above equation when in logarithmic form is somewhat difficult and is probably responsible for the confusion.

Messrs. Telfair and Nason are correct in saying that 3 parameters are necessary to define the state of stress. However, the fact that most materials fail either by yielding or fracture and that yielding results when a limiting value of maximum shearing stress $\tau_{\max.}$ is exceeded whereas fracture results when a limiting value of maximum normal stress $\sigma_{\max.}$ is exceeded has led many people to assume that the third parameter (the principal stress of intermediate value) has little significance. The truth of this assumption is, of course, open to question.

---

[4] Assistant Professor and Instructor, respectively, of Theoretical and Applied Mechanics, College of Engineering, University of Illinois, Urbana, Ill.

INDENTATION HARDNESS OF PLASTICS

By Ladislav Boor[1]

Synopsis

A study was made of the indentation behavior of typical soft metals and plastics on the Rockwell hardness tester. The proportion of the indentation which is recovered on removal of the major load is enormously greater for plastics, and hence measurements based on this recovered depth are not a true measure of resistance to indentation.

A procedure was developed which permits measurement of indentation depth under major load. These values of indentation for various loads were then related by means of the Meyer equations, and a method of analyzing the curves was suggested.

Two new scales of Rockwell indentation hardness are proposed to cover the plastics now on the market, which extend the useful range of the instrument into the softer class of plastics.

The degree of reproducibility of values among six different machines is shown. Data are presented on the effect of thickness and layering of samples on indentation hardness.

Attempts to define hardness as a single precisely determinable physical property of a solid substance have to date met with little success. The papers presented at the A.S.T.M. Symposium on Hardness,[2] and the discussion following, have emphasized the complexity of the various contributing factors inherent in the process of measuring hardness. The fact remains, however, that many methods of measuring indices of hardness are widely used for metals, and that these indices are useful in the interpretation of their internal structure and service behavior.

For the purpose of this investigation, hardness was defined as resistance to indentation, and the field was further limited to the case of a spherical indenter. During the progress of the work, it was found desirable to fix the size of the indenter and to maintain constant certain time factors involved in the measurement.

Since indentation hardness has long been accepted as a useful index of the properties of metals, it was natural that this test should be applied also to the plastics. Brinell and Rockwell values are often quoted in sales literature and properties charts, but it has been difficult to arrive at a unified concept of indentation hardness for the wide variety of plastics now on the market.

The Brinell method, which involves the measurement of the diameter of the indentation, has definite limitations. The edge of the indentation is usually poorly defined; sometimes the material piles up around the edge. Many of the plastics recover a large proportion of indentation within a few seconds, which is followed by a further slow creeping recovery which renders valueless a measurement of the impression after the load has been removed. These effects have also been described by Starkie (**1**).[3] In Kline and Axilrod's study of transparent plastics for aircraft (**2**), hardness numbers determined in several ways are shown. Although there was good agreement in the classification of the hardest and softest groups, there were some discrepancies in the order of hardness in the series when measured by the different methods. The quantitative separation of hardness index from the hardest to the softest was also quite different among the various procedures.

---

[1] Physics Division, American Cyanamid Co., Stamford Research Laboratories, Stamford, Conn.

[2] *Proceedings*, Am. Soc. Testing Mats., Vol. 43, p. 803 (1943).

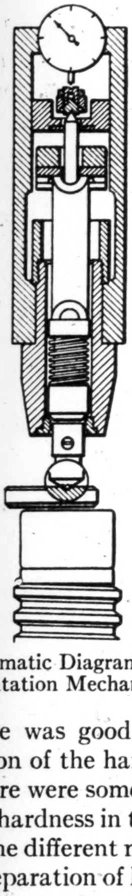


FIG. 1.—Schematic Diagram of Rockwell Indentation Mechanism.

In an attempt to rationalize the various factors entering into a determination of indentation hardness, a study was made of the Rockwell hardness tester, which is one of the well-known instruments used for this purpose.

In brief, the instrument consists of a C frame, with an elevating screw for positioning the sample in contact with the indenter and a means of applying a small initial load, called the "minor load." A dial gage is then set at zero, which represents the position of the indenter at the start of the test. A heavier load of known magnitude is then applied to the indenter at a controllable rate, allowed to act for a certain time, then the major load is released, leaving the minor load still on the indenter. The hardness index is read as the increase in dial gage reading caused by the indentation due to the major load.

A schematic diagram of the head of the Rockwell tester is shown in Fig. 1. The dial gage, fastened to the upper part of the C frame, indicates the relative vertical movement between the frame and the plunger rod. Obviously, then, a vertical movement downward of the plunger rod with the frame stationary (indentation into the specimen) or a vertical movement upward of the C frame with the indenter spindle stationary (spring of the frame when load is applied to the indenter) will register in the same direction on the dial gage. This spring of the frame under major load does not enter into the ordinary method of hardness determination since readings are made before the major load is applied and after it has been removed.

In making Rockwell indentation tests on the softer plastics, a rapid gyration of the needle is observed upon applying and removing the major load. These deflections represent the movement of the indenter with respect to the frame, including the spring of the frame, plus the disturbance of the test material under the indenter. Our first problem was to obtain an accurate record of these movements at the various stages of the Rockwell test procedure.

---

[3] The boldface numbers in parentheses refer to the reports and papers appearing in the list of references appended to this paper, see p. 991.

In order to arrive at some means of measuring indentation under load, it was necessary to establish the magnitude and reproducibility of the spring in the frame, in terms of dial gage reading, for various loads. This was done by using a soft copper block as sample and the particular indenting sphere ($\frac{1}{2}$ in. in most of the work described here). The sample was raised to the normal starting position with the minor load applied and the dial gage set at 0. The major load was then applied by tripping the lever. The dial gage then recorded the vertical distance of indentation plus the spring of the frame and any other elastic compressive deformation of the indenter spindle and indenter. This operation was repeated several times without moving the copper block, until the deflection of the dial gage became constant, that is, no further indentation took place, and only the spring of the frame remained. This value, in terms of dial gage divisions for various major loads is shown in Fig. 2 for two instruments. These lines represent spring of the frame and indenter in addition to that produced by the minor load (10 kg); hence they intersect the load axis at 10 kg. They represent a practically elastic behavior of the frame under stress, and, once determined, are reproducible to a high degree of precision.

The use of the spring correction enables us to estimate the depth of indentation on any specimen, under load, as long as this load is actually being delivered to the indenter.

This correction may be applied in several ways. On instruments having an unlimited rotation of the dial bezel, the scale divisions representing the correction may be set to the right of the 0 point by turning the bezel; then application of the major load, with no indentation should cause the needle to swing to 0 and stop. Any reading to the left of 0 then represents indentation into the specimen. On machines having a limited rotation of the bezel, the dial is set to 0 at the start, the major load is applied, and the correction is then subtracted from the total scale divisions of penetration observed under the major load. It is to be noted that the numbers shown on the standard dial gage are not used, but the actual scale divisions representing indentation are

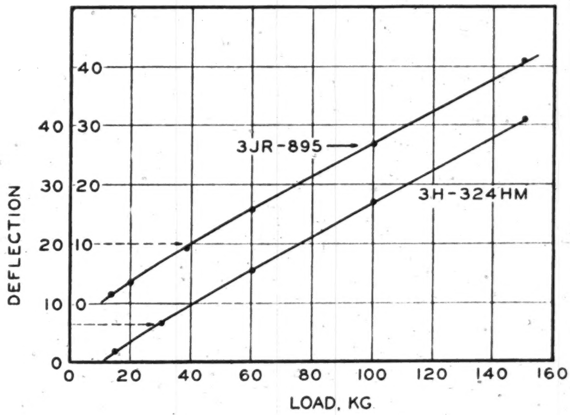
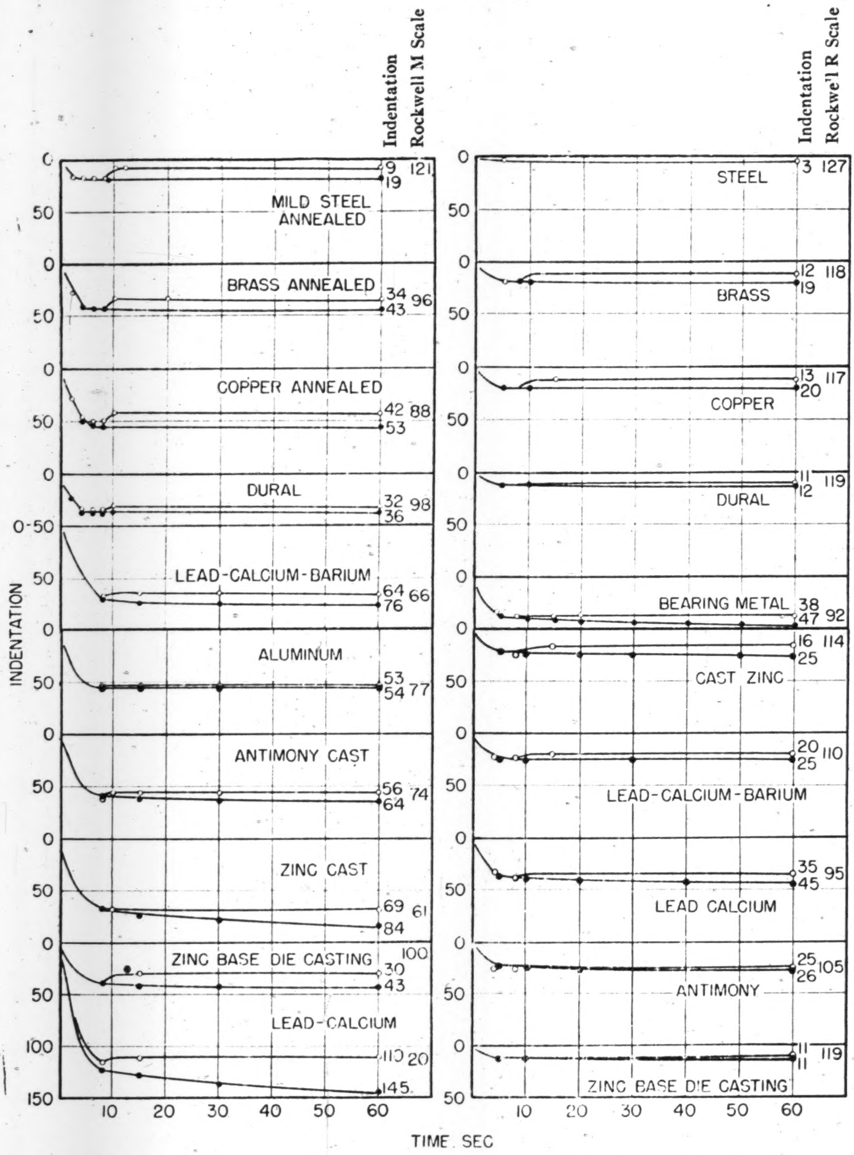


FIG. 2.—Spring of Frame on Two Rockwell Hardness Testers

counted. This is easy with a little practice, the 50 scale division point can be readily located opposite the 0 point, and units of ten may be estimated from this. A full revolution of the needle of course represents 100 divisions, and any movement beyond this is easily estimated.



¼-in. Ball, 100-kg. Load. ½ in. Ball, 60-kg. Load.

FIG. 3. Time-Indentation Relations on Typical Metals.

One of the important limitations of the Standard Rockwell is the total depth of penetration measurable on the dial gage with the major load on the indenter before reaching the end of its free movement. This was fixed, on the instrument used, at 1½ revolutions of the dial gage (150 scale divisions) representing about 0.012 in. of actual penetration.

INDENTATION—TIME STUDIES

Since the movement of the pointer during some phases of the test was quite rapid, and difficult to read with any accuracy, a record of dial readings was made by photographing the dial gage, at 2-sec. intervals, on 16-mm. film. The dial gage readings, with the proper corrections, were then plotted against time, up to 60 sec. total time of test.

The dashpot of the machine was adjusted according to the A.S.T.M. Standard Methods of Testing Sheet and Plate Materials Used in Electrical Insulation (D 229 – 43),[4] namely, so that the operating handle completed its travel in 4½ sec. with no specimen in the machine and with the machine set up to apply a major load of 100 kg. This adjustment was maintained throughout all of the tests described. The instrument was used in a conditioned room at 78 F. and 50 per cent relative humidity and all materials were tested under these conditions.

TABLE I.

M 187.........	Mineral-filled melamine
M 592.........	Mineral-filled melamine
BM 261.......	Mineral-filled phenolic
BM 120.......	Wood-flour-filled phenolic
BM 3510.......	Rag-filled phenolic
XXX H 401....	Paper-base phenolic laminate
X P 208 D.....	Paper-base phenolic laminate
Mel. Kraft.....	Paper-base melamine laminate
CR 39.........	Allyl resin—clear
Fibestos.......	Cellulose acetate—Monsanto
Plastacele......	Cellulose acetate—Dupont

Graphs of indentation against time were made by two methods:

1. Major load applied for 60 sec.
2. Major load applied for 8 sec., then released and minor load left on for 45 sec. (D 229 – 43). Both ¼-in. ball with 100-kg. major load (M scale) and ½-in. ball with 60-kg. major load (R scale) were used. Most of the curves show readings up to 60 sec. total elapsed time from start of test. In practically all materials, there was no significant movement of the pointer, between 53 sec. total elapsed time (8 sec. major load plus 45 sec. minor load) and 60 sec. total elapsed time.

Figure 3 shows the behavior of typical metals under these conditions.

It can be seen that practically all of the indentation occurs within the first 4 to 6 sec. With the harder metals, no further movement takes place up to 60 sec. total indentation time. In the softer metals, the time for indentation is extended, as shown in the curves. When the major load is removed after 8 sec., there is a slight instantaneous elastic recovery, after which there is no further change up to 60 sec. The same behavior obtains when the ½-in. ball and 60 kg. load are used, with correspondingly smaller indentation.

The important feature of these curves is that the indentation reading observed, after the removal of the major indenting load, is, for all practical purposes, very close to the actual depth of the indentation under the major load. In other words, the recovery of the indentation after removal of the major load is negligible.

The same procedure was carried out on a series of typical plastic samples. Materials not otherwise identified are shown in Table I. They were tested with the ¼-in., 100-kg. and ½-in., 60-kg. combinations. These graphs appear in Figs. 4 and 5.

In the columns at the right are shown:

(*a*) The total indentation under major load, applied for 60 sec.

(*b*) The residual indentation 45 sec. after removal of major load, having been previously applied for 8 sec.

---

[4] 1943 Supplement to Book of A.S.T.M. Standards, Part III, p. 64.

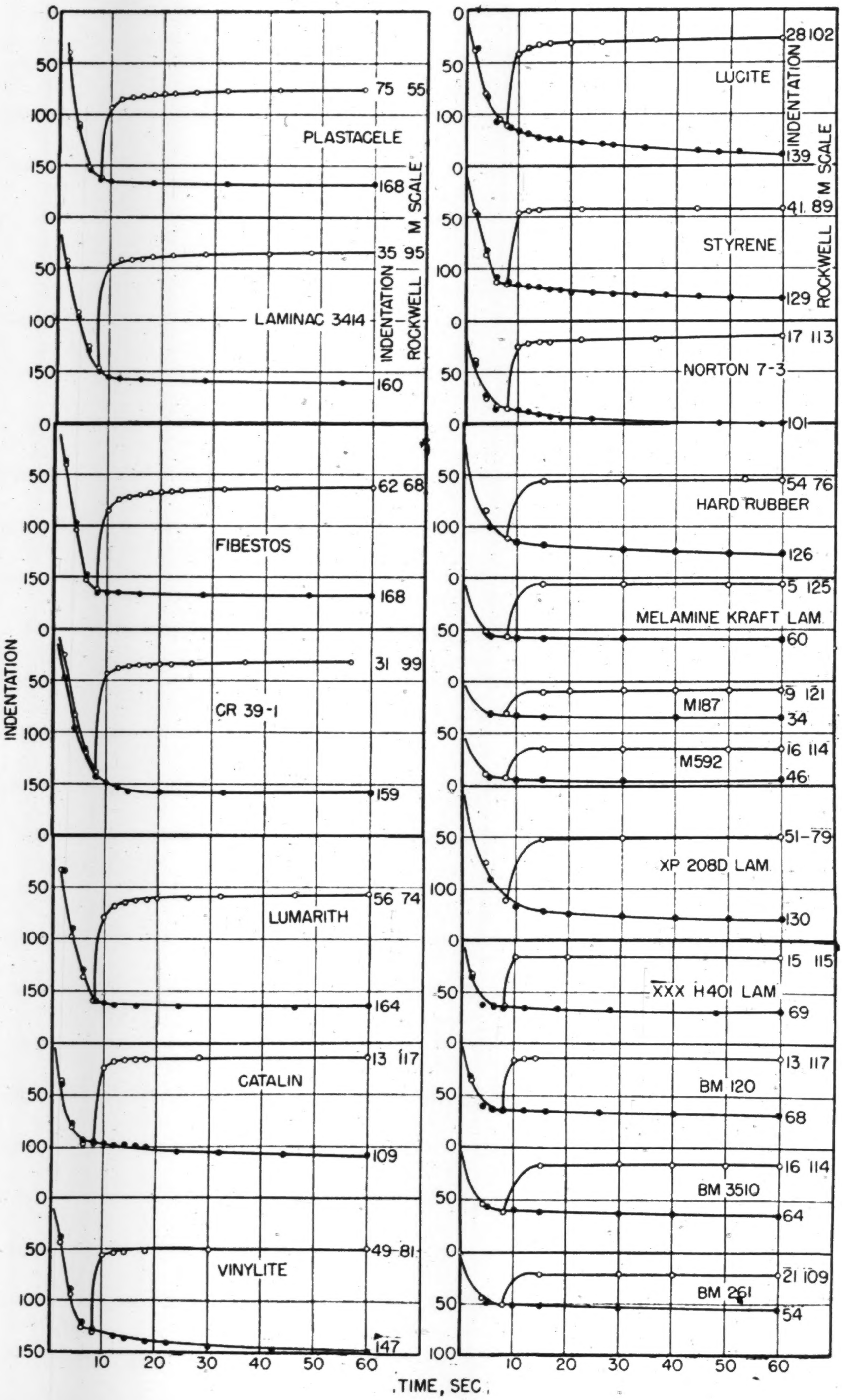


FIG. 4.—Time-Indentation Relations on Typical Plastics, ½-in. Ball, 100-kg. Load.

(*c*) The corresponding Rockwell number (M and R scale), which is 130 minus the residual indentation in scale divisions.

The significant values for the 20 typical materials tested, are shown in Table II. They are arranged in order of their depth of indentation under major load.

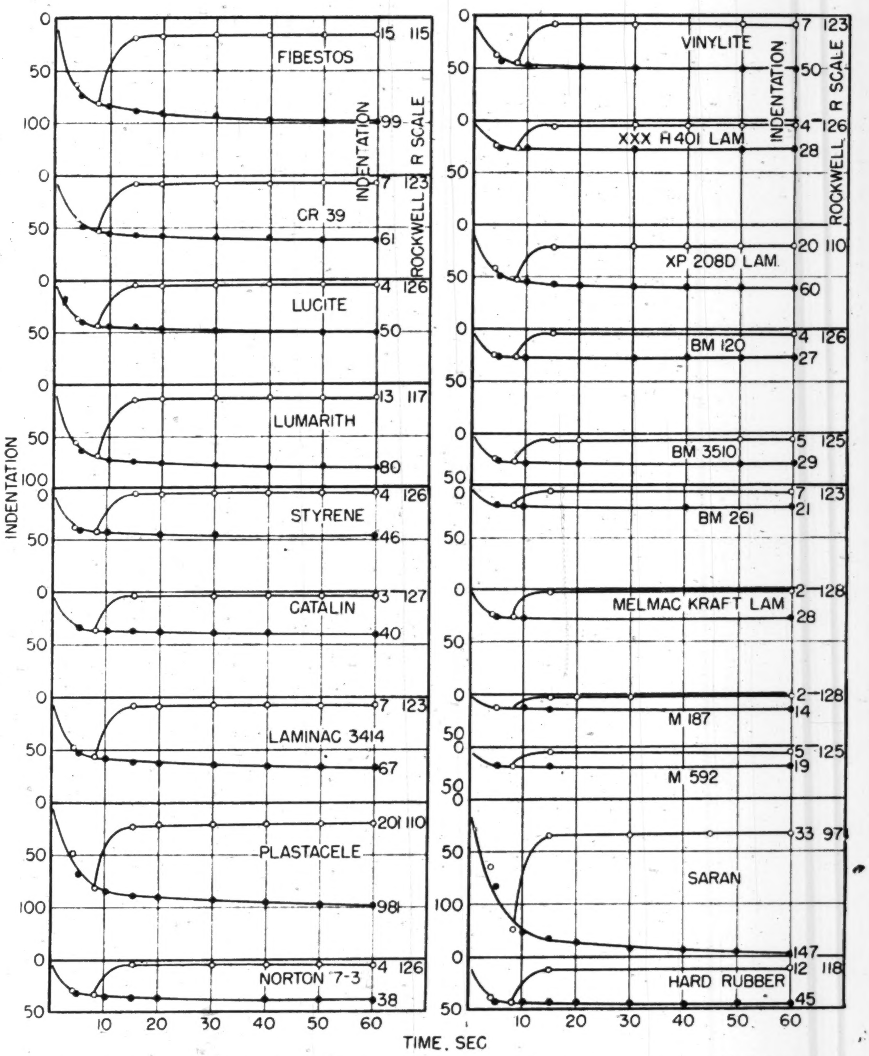


FIG. 5.—Time-Indentation Relations on Typical Plastics, ½-in. Ball, 60-kg. Load.

We have here an entirely different behavior from that shown by the metals. On removal of the major load a large portion of the indentation is recovered within a few seconds, followed by a slow creeping recovery.

It is apparent that the rank according to column A has no relation to the rank in terms of the M or R scale; materials like M592 and Norton, having nearly the same M scale value are widely different in indentation under load. Vinylite which is harder than hard rubber on the M scale, is considerably less resistant to indentation under load.

TABLE II.—INDENTATION RELATIONS.

	Thickness, in.	Indentation: After 60 sec. Major Load	Indentation: M Scale, 45 sec. after Removal of Major Load	Rockwell Hardness, M or R scale	Indentation after 8 sec. Major Load	Recovery, Col. D − Col. B, scale divisions	Recovery, Col. E / Col. D × 100, per cent	Classification[b]
		A	B	C	D	E	F	G
¼-in. Ball, 100-kg. Load								
M 187	0.50	34	9	121	31	22	71	2
M 592	0.50	46	16	114	43	27	63	3
BM 261	0.136	54	21	109	51	30	59	4
Mel Kraft	0.50	60	5	125	57	52	91	1
BM 3510	0.141	64	16	114	61	45	74	2
BM 120	0.128	68	13	117	63	50	79	2
XXX H 401	0.123	69	15	115	64	49	77	2
Norton	0.119	101	17	113	85	68	80	1
Catalin	0.119	109	13	117	95	82	86	1
Hard rubber	0.126	126	54	76	112	58	52	4
Styrene	0.230	129	41	89	115	74	65	3
XP 208 D	0.125	130	51	79	112	61	54	4
Lucite	0.125	139	28	102	111	83	75	2
Vinylite	0.251	147	49	81	128	79	62	3
CR 39	0.122	159	>120[a]	...	...	...	...	...
Laminac	0.185	160	>120	...	...	...	...	...
Lumarith	0.194	164	>120	...	...	...	...	...
Fibestos	0.213	168	>120	...	...	...	...	...
Plastacele	0.130	168	>120	...	...	...	...	...
Saran	0.360	170	>120	...	...	...	...	...
½-in. Ball, 60-kg. Load								
M 187	0.50	14	2	128	13	11	84.7	2
M 592	0.50	19	5	125	18	13	72	3
BM 261	0.136	21	7	123	20	13	65	4
Mel Kraft	0.50	28	2	128	26	24	92	1
BM 3510	0.141	29	5	125	26	21	81	2
BM 120	0.128	27	4	126	26	22	84.5	2
XXX H 401	0.123	28	4	126	26	22	84.5	2
Norton	0.119	38	4	126	33	29	88	1
Catalin	0.119	40	3	127	35	32	91.5	1
Hard rubber	0.126	45	12	118	41	29	71	3
Styrene	0.230	46	4	126	42	38	90.6	1
XP 208 D	0.125	60	20	110	53	33	62	4
Lucite	0.125	50	4	126	43	39	90.6	1
Vinylite	0.251	50	7	123	46	39	85	2
CR 39	0.122	61	7	123	53	46	87	...
Laminac	0.185	67	7	123	57	50	88	...
Lumarith	0.194	80	13	117	68	55	81	...
Fibestos	0.213	99	15	115	81	66	81	...
Plastacele	0.130	98	20	110	81	61	75	...
Saran	0.360	147	33	97	128	95	74	...

[a] 150 scale divisions − 30 divisions correction for spring of frame.

[b] See description of classifications under Table III.

Table III shows a classification of the materials tested by both scales in order of their percentage recovery. It is seen that the degree of recovery is not necessarily associated with either high or low resistance to indentation, and that the ½-in., 60-kg. (R scale) condition has a tendency to rank Styrene, Lucite, and hard rubber higher than the ¼-in., 100-kg. (M scale) test. This is probably due to the less severe indentation and correspondingly less permanent deformation of the material under the ½-in., 60-kg. test.

Since the degree of recovery is in no way related to the resistance to indentation under load, it becomes clear that the relation of residual indentation (M or R scale) to the indentation under load, which is valid when testing metals, is not suitable as a basis for comparing indentation hardness of plastics. The situation is somewhat analogous to measurement of elongation in a tension test on a semi-elastic material by measurement of the length of the two broken halves.

TABLE III.—INDENTATION *versus* RECOVERY.

Rank	¼-in. Ball, 100-kg. Load			½-in. Ball, 60-kg. Load	
	Material	Recovery, per cent	Classification[a]	Recovery, per cent	Classification[b]
4	Mel Kraft	91	1	92	1
8	Norton	80	1	88	1
9	Catalin	86	1	91.5	1
1	M 187	71	2	84.7	2
5	BM 3510	74	2	81	2
6	BM 120	79	2	84.5	2
7	XXX H 401	77	2	84.5	2
13	Lucite	75	2	90.6	1
2	M 592	63	3	72	3
11	Styrene	65	3	90.6	1
14	Vinylite	62	3	85	2
3	BM 261	59	4	65	4
10	Hard Rubber	52	4	71	3
12	XP 208 D	54	4	62	4

[a] Class 1 = 80 per cent or over.
2 = 70 to 80 per cent.
3 = 60 to 70 per cent.
4 = 60 per cent or less.

[b] Class 1 = 88 per cent or over.
2 = 80 to 90 per cent.
3 = 70 to 80 per cent.
4 = 70 per cent or less.

The measurement of indentation under load is utilized in other procedures for measuring indentation hardness, such as the Pfund hardness meter for paint films (3), and the R.A.B.R.M. hardness tester for leather (4). Most of the portable hardness testers for rubber use the same principle.

MEASUREMENT OF RESISTANCE TO INDENTATION UNDER LOAD

On the assumption that the resistance to indentation under load might be a useful index of the structure and service behavior of plastics, further work was carried out with the purpose of establishing some test procedure based on the above findings, utilizing the Standard Rockwell instrument.

Table II shows that the $\frac{1}{4}$-in., 100-kg. combination will indent the softer plastics beyond the limit of the useful stroke of the standard machine. The $\frac{1}{2}$-in., 60-kg. combination, on the other hand, will give measurable indentations in the hardest of the mineral filled thermosetting materials at one end of the scale and, at the other extreme, will still give values on the softer thermoplastics. Since the demand at present is for a method of measuring in the soft range, it appeared possible that by using the $\frac{1}{2}$-in. ball and loads of 60 kg. and lower, a scale covering a wide range of hardness might be devised. The $\frac{1}{2}$-in. ball also has some desirable features which will be brought out later.

LOAD—INDENTATION RELATIONS

The earliest systematic study of the relation of load to effect of a spherical indenter was carried out by Brinell. He used the relation

$$\text{Brinell Number} = \frac{\text{Load}}{\text{Spherical area of impression}}$$

This requires measurement of the indentation produced by the loaded indenter, which is impractical in plastics.

Meyer in 1908 devised a method of expressing the change in hardness produced by successive indentations with increasing loads. These two methods and their application to the testing of metals have been under investigation by Heyer (5).

Meyer found that in most solid substances the relation between load L and diameter of the impression, *d*, for a ball of given diameter may be expressed by the equation

$$L = Kd^n$$

where K is an index of specific hardness and n is a coefficient representing the rate of hardness increase with depth of indentation.

The "Meyer Hardness," M is given by the expression

$$M = \frac{L}{\pi d^2/4}$$

If the load L is given in kilograms and diameter d in millimeters, this equation represents the mean pressure, in kilograms per square millimeter of projected area, existing at the moment when the loaded indenter penetrates to a depth (and area) just sufficient to support the loaded indenter.

TABLE IV.

Rockwell Dial Scale Divisions	Area, sq. mm.
5	0.41
10	0.81
20	1.62
40	3.22
80	6.41
160	12.70

If a material does not change in resistance to indentation as an indenter is progressively forced into the surface by increasing loads (M constant), then projected area of indentation, or the square of its diameter, would increase in direct proportion to load.

In the Rockwell test, loads of known weight can be precisely applied. We cannot measure the diameter of the indentation under load directly, but we have an accurate measure of the depth of indentation caused by the increase from minor to major load, plus elastic deformation of the test specimen.

TABLE V.—SUMMARY—OBSERVED INDENTATION UNDER LOAD.

½-in. Ball, 15 sec.

Rank	Material	30-kg. Load	60-kg. Load	100-kg. Load	150-kg. Load	Factor $\frac{60\text{ kg.}}{30\text{ kg.}}$
1......	M 187	7	15	23	32	2.14
2......	M 592	9	20	31	45	2.22
3......	BM 261	10	22	35	50	2.20
4......	BM 120	13	27	43	62	2.08
5......	BM 3510	13	28	44	61	2.16
6......	XXX H 401	14	29	45	63	2.08
7......	Mel Kraft	14	30	45	62	2.14
8......	Norton	17	36	58	82	2.12
9......	Catalin	19	38	61	88	2.00
10......	Hard Rubber	19	43	70	104	2.26
11......	Styrene	21	44	73	108	2.10
12......	Lucite	22	47	75	110	2.14
13......	Vinylite	22	48	80	119	2.18
14......	CR 39	27	58	95	139	2.15
15......	XP 208 D	27	59	88	119	2.18
16......	Laminac	29	63	102	141	2.17
17......	Lumarith	34	76	124	...	2.24
18......	Fibestos	41	88	147	...	2.14
19......	Plastacele	42	93	155	...	2.22
20......	Saran	64	137		...	2.14

At this point we may utilize an interesting property of the $\frac{1}{2}$-in. ball when used on the Standard Rockwell. Calculation of the diameter of the intersection of a plane with the $\frac{1}{2}$-in. sphere at varying depths shows that for small increments of depth of this ball, namely, about 0.012 in., the depth is, for practical purposes, proportional to the area. Table IV shows the areas, of the intersection of a plane and the $\frac{1}{2}$-in. sphere for various heights in Rockwell dial scale divisions.

Since this is about the limit of usable depth of indentation, the relationship of depth to area of indentation is close enough to linearity for practical purposes. This gives a means for testing the relation of load to area (or depth) of indentation stated in the Meyer equation:

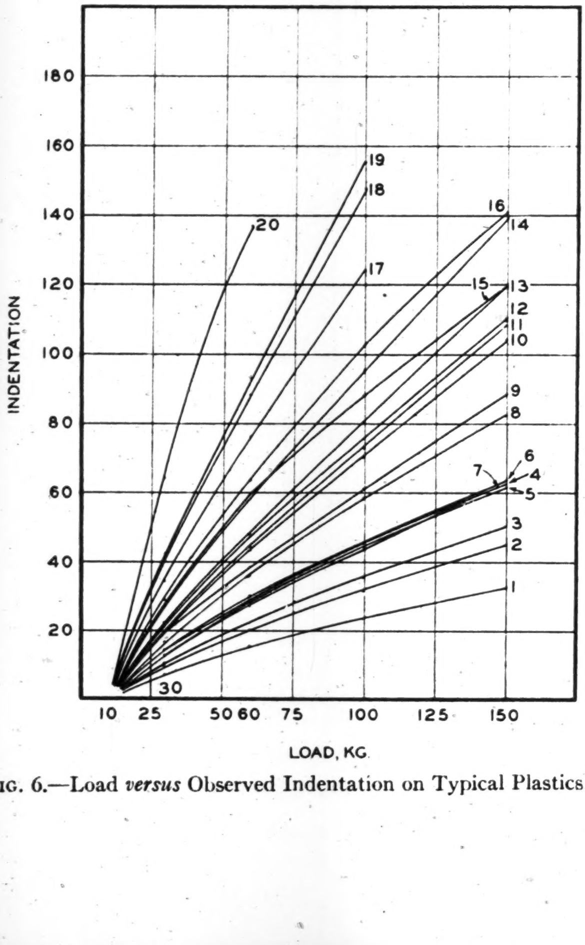


FIG. 6.—Load *versus* Observed Indentation on Typical Plastics.

Measurements were made of the depth of indentation with various loads in the Rockwell machine, using the $\frac{1}{2}$-in. ball. The time, instead of 60 sec. used in the first part, was reduced to 15 sec., since most materials indent very slowly after this time interval. The correction for the spring of the frame was determined for each weight, and this correction was subtracted, so that the values represent the indentation into the sample (assuming no disturbance of material around the indentation). Since the minor load on the machine is 10 kg., enough to cause a definite initial indentation, the readings represent the additional increment of indentation caused by the load used. The 30-kg. weight was constructed to fit this particular machine, and had an actual weight of 990 g.[5]

The results of tests on the twenty samples previously tested are shown in Table V. They are listed in order of increasing depth of indentation at 60-kg. load. This is slightly different from the original listing in Table II because of small differences in depth attained at the 15-sec. interval as compared to the 60-sec. period. The last column in Table V is the factor relating the observed indentation at 60-kg. to that at 30-kg. They are plotted in Fig. 6.

It should be noted that these curves all start at 10 kg. (minor load) where the indentation indicated is 0. This is not strictly true, since the 10-kg. minor load produces a significant indentation on all the materials. These relations would be more useful if we had a more accurate picture of the curves at the lower end. Since we have no way of readily measuring the indentation produced by the minor load (10 kg.) we shall make certain assumptions.

We can measure the increment of additional indentation produced by the 30-kg. load over that produced by the 10-kg. minor load. Therefore, we know the change in depth produced by 30 − 10, or 20-kg. load. Since depth is proportional to area of indentation, we can use the depth directly instead of the area. If we can assume that, in this range of indentation, the relationship

$$\text{Hardness} = \frac{\text{Load}}{\text{Area}}$$

is valid, then since area is proportional to depth, the relation

$$\text{Hardness} = \frac{\text{Load}}{\text{Depth}}$$

should be equally true.

The depth of indentation under the 10-kg. load should then be 10/20 or $\frac{1}{2}$ of the increment of indentation produced by the increase of load from 10 to 30 kg., and the total indentation under any load should be this depth plus the indentation observed from the 10-kg. minor load to any major load used. These values for the 20 samples are shown in Table VI. The factor relating total depth of indentation at 60 and 30 kg., respectively, is shown in the last column. The values in Table VI are plotted in Fig. 7. The slight curvature of these lines suggests that they might follow some exponential relation, as was observed by Meyer in his original investigation on metals.

If we consider the first Meyer equation, given above, the d or diameter of the impression may be replaced by area a. We can then write

$$L = Ka^q$$

or, in the logarithmic form,

$$\log L = \log K + q \log a$$

If it is assumed that depth d is proportional to area a

$$\log L = \log K + q \log d$$

---

[5] Various models of the Rockwell machine differ in their ratios of lever arms. The manufacturer should be consulted concerning the weight required for any specific model.

TABLE VI.—SUMMARY—TOTAL INDENTATION UNDER LOAD.

½-in. Ball, 15 sec.

Rank	Material	10-kg. Load, est.	30-kg. Load	60-kg. Load	100-kg. Load	150-kg. Load	Factor $\frac{60\text{ kg.}}{30\text{ kg.}}$
1......	M 187	3.5	10.5	18.5	26.5	35.5	1.76
2......	M 592	4.5	13.5	24.5	35.5	49.5	1.81
3......	BM 261	5	15	27	40	55	1.80
4......	BM 120	6.5	19.5	33.5	49.5	68.5	1.72
5......	BM 3510	6.5	19.5	34.5	50.5	67.5	1.77
6......	XXX H 401	7	21	36	52	70	1.71
7......	Mel Kraft	7	21	37	52	69	1.76
8......	Norton	8.5	25.5	44.5	66.5	90.5	1.74
9......	Catalin	9.5	28.5	47.5	70.5	97.5	1.67
10......	Hard Rubber	9.5	28.5	52.5	79.5	113.5	1.84
11......	Styrene	10.5	31.5	54.5	83.5	118.5	1.73
12......	Lucite	11	33	58	86	121	1.76
13......	Vinylite	11	33	59	91	130	1.79
14......	CR 39	13.5	40.5	71.5	108.5	152.5	1.77
15......	XP 208 D	13.5	40.5	72.5	101.5	132.5	1.79
16......	Laminac	14.5	43.5	77.5	116.5	155.5	1.78
17......	Lumarith	17	51	93	141	...	1.82
18......	Fibestos	20.5	61.5	108.5	167.5	...	1.76
19......	Plastacele	21	63	114	176	...	1.81
20......	Saran	32	96	169	...	...	1.76

If log L is plotted against log d the constant K is the value of L when indentation depth is one and q is the slope of the line.

If load is directly proportional to depth, q becomes 1; values of q greater than one indicate that the material increases in hardness with indentation, and values of q less than one show a progressive decrease in hardness with increasing depth of indentation. We are assuming that no extraneous effects such as piling up of the material around the edges of the indentation or a rounding of the boundary between the original plane of the surface and the edge of the indentation occur. Such effects are well described by Williams (6).

The values for the 20 test materials

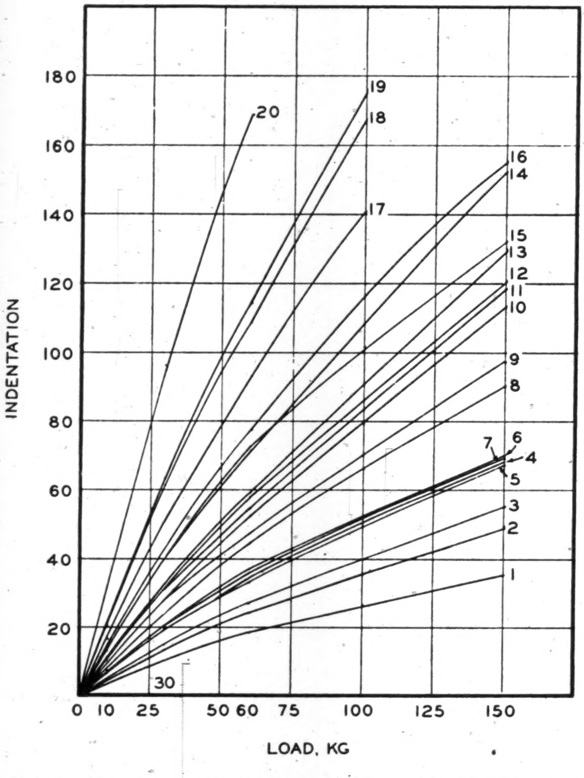


FIG. 7.—Load *versus* Total Indentation on Typical Plastics.

are plotted on logarithmic coordinates in Figs. 8 and 9. One group of materials shown in Fig. 8 shows a practically linear relation at loads between 30 and 150 kg. with a slope somewhat greater than one.

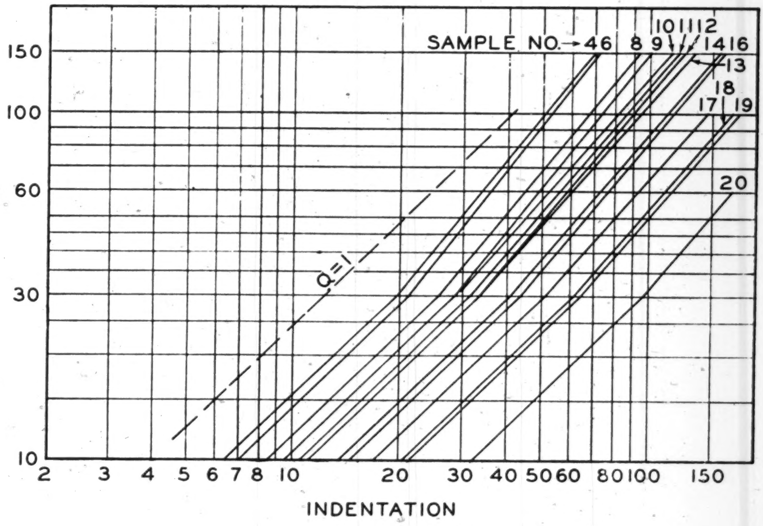


FIG. 8.—Load *versus* Indentation, Log—Log Scale.

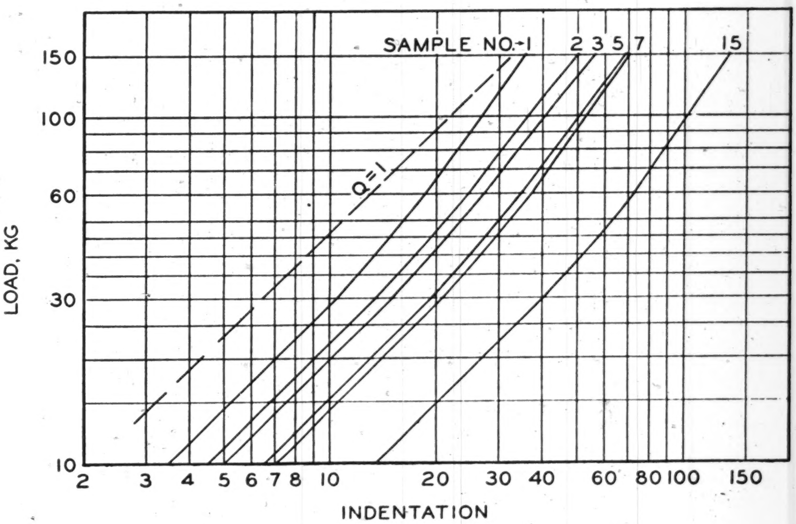


FIG. 9.—Load *versus* Indentation, Log—Log Scale.

The value of the intercept K may be obtained as follows:

Let L_1 represent the lesser of the loads used and d_1 its corresponding total depth of indentation, and L_2 and d_2 the respective values for the greater of the loads. Then

$$\log K = \frac{\log d_2 \log L_1 - \log d_1 \log L_2}{\log d_2 - \log d_1}$$

K is the intercept on the load axis when $d = 1$, or is the load, based on the straight line defined by the above coordinates, which will produce an indentation of 1.

With K known, q may be calculated from the relation

$$q = \frac{\log L - \log K}{\log d}$$

The slope may also be obtained without using K from the equation

$$q = \frac{\log L_2 - \log L_1}{\log d_2 - \log d_1}$$

or may be determined directly from the graph[6] by dividing the measured distance between the two loads by the distance between their corresponding depths of indentation.

K is of theoretical interest since it is an extrapolated value and will rank materials in a certain order of their resistance to indentation at extremely low levels of indentation. The exponent q measures the rate of change of indentation with load if this relation follows an exponential form.

The materials shown in Fig. 8 are listed in Table VII and the values of q have been calculated.

This group contains all the unfilled plastics, wood-flour-filled phenolic, XXX paper-base laminate, and hard rubber. In the case of wood-flour-filled phenolic and paper-base laminate, it may be logical to interpret the higher value of q on the basis of the behavior of the filler, consisting of a cellular or fibrous structure which is progressively packed by successively deeper indentation. In the case of the clear, unfilled plastics such as Catalin, Norton, and Laminac, this theory will not serve unless it is assumed that the molecular elements of structure, such as fibrils, micelles or chain lengths, behave somewhat like the fibrous fillers in the first two materials mentioned. Any piling up of material around the edges would result in an area of support greater than that calculated from the depth and would result in an apparent increase of hardness with increasing depth of indentation.

Another group exhibiting somewhat different behavior is shown in Fig. 9.

TABLE VII.

Sample	Material	Slope, q
No. 4	BM 120	1.28
No. 6	XXX H 401	1.34
No. 8	Norton	1.27
No. 9	Catalin	1.31
No. 10	Hard rubber	1.16
No. 11	Styrene	1.21
No. 12	Lucite	1.24
No. 13	Vinylite	1.17
No. 14	CR 39	1.21
No. 16	Laminac	1.26
No. 17	Lumarith	1.19
No. 18	Fibestos	1.20
No. 19	Plastacele	1.17
No. 20	Saran	1.23

TABLE VIII.

Sample	Material	Slope, q
No. 1	M 187	1.41
No. 2	M 592	1.30
No. 3	BM 261	1.29
No. 5	BM 3510	1.37
No. 7	Melamine Kraft Lam.	1.47
No. 15	XP 208 D	1.52

Instead of a constant slope between 30- and 150-kg. load, these materials show a perceptible increase of slope between 30 and 60 kg. which then remains fairly constant up to 150 kg.

The slope of the nearly straight-line portion of the curve between 60 and 150 kg. for these materials are given in Table VIII. They are all compounds containing fillers of various types; the XP paper-base laminate shows the highest value of q among the group.

Since we do not know the exact shape of the curve below the 30-kg. load, we have no evidence for or against the so-called "case hardened" effect often mentioned as a property of some plastics cured by contact with the hot mold or by solvent evaporation from the surface. Whether the slope of these lines gradually decreases to 1 or less may be revealed by further investigation. Some modification of the present instrument to provide for measurements of indentation with loads from 0 to 30 kg. might show the true shape of the curve for small increments of load. An increase in the measurable vertical movement of the indenter would also serve to explore the relationships at indentations greater than 150 scale divisions (0.012 in.).

---

[6] The coordinates on the two axes must be on the same linear scale.

A SIMPLE INDENTATION HARDNESS TEST

The analysis described might prove useful in the critical examination of specific materials or formulations but does not lend itself to rapid and convenient testing. Since the functions as plotted above are not entirely straight lines, nor do they have a constant slope, we cannot arrive at a simple expression containing an intercept and slope to define a characteristic line for any material under all conditions of loading.

TABLE IX.

Grade	Observed Indentation			Total Indentation			
	30-kg. Load	60-kg. Load	Factor, $\frac{60\text{ kg.}}{30\text{ kg.}}$	10-kg. Load (est.)	30-kg. Load	60-kg. Load	Factor, $\frac{60\text{ kg.}}{30\text{ kg.}}$
H8	30	64	2.14	15	45	79	1.76
H4	36	81	2.25	18	54	99	1.83
H	48	105	2.18	24	72	129	1.79
MH	46	103	2.24	23	69	126	1.82
M	58	128	2.20	29	87	157	1.80
S2	62	139	2.24	31	93	170	1.83
S4	74	161	2.18	37	111	198	1.78
S9	65	142	2.18	32.5	97.5	174.5	1.79

With these limitations in mind, it is still possible to select a set of conditions which will give a fair index of indentation hardness. It can be seen from Tables V and VI that the indentation for the 60-kg. load is approximately double that for the 30-kg. load.

To determine the feasibility of such a basis for a single unified scale to cover most of the plastics, the 20 samples previously described were supplemented by 8 additional samples of cellulose acetate,[7] 0.290-in. thick, covering the range from grade H8 to S9. These were tested with 30-kg. and 60-kg. loads. The same assumption was made as before in estimating the depth of indentation with the minor (10-kg. load). The results are given in Table IX.

It is to be noted that the depths of indentation with both 30- and 60-kg. loads are not strictly in line with their flow temperatures as indicated by the grade designation.

Referring now to the factors relating, first, the observed indentation from 10-kg. minor load to 30-kg., and from 10-kg. minor load to 60-kg., it is seen that they vary from 2.00 to 2.26 with an average of 2.17. If the Meyer relationship is valid and the exponent q is 1, then the factor relating these depths of indentation should be 2.5, since we apply $30 - 10$ or 20 kg. additional in the first case and $60 - 10 = 50$ kg. additional in the second.

The factor relating total indentation (estimated indentation at 10 kg. plus additional observed indentation at 30 kg. and at 60 kg.), assuming the Meyer relationship and $q = 1$, should be 2.0. The actual values vary between 1.67 and 1.84, averaging 1.78. Both of these approaches point to the same conclusion, that is, that at this level of loading the load and indentation are not proportional.

Neither of these simple methods, therefore, will provide the basis for a single scale utilizing the two weights. Each weight, however, can be used within its useful range to measure indentation hardness under load and can carry its own designation. Since we have set 150 scale divisions as the limit of penetration, then 150 − scale reading will give us a set of numbers in proportion to resistance to indentation, or to indentation hardness. In the group of materials listed, everything down to Saran and all of the acetates except S4 can be measured with the 60-kg. load. The 30-kg. load can be used for materials overlapping in hardness into the 60-kg. range (150 scale divisions of indentation with 60-kg. load will give about 70 divisions of indentation with 30-kg. load) and ranging downward to very soft synthetic shoe sole compositions easily indented with the fingernail. When measuring such soft materials, the 10-kg. minor load causes a perceptible creep before the major load is applied and requires setting the 0 point as quickly as possible.

---

[7] Samples supplied by J. H. Teeple, Celanese Celluloid Corp.

TABLE X.

Rank	Material	½-in. Ball, 60-kg. Load, 15 sec.		½-in. Ball, 30-kg. Load, 15 sec.	
		Indentation	α Scale	Indentation	β Scale
1	M 187	15	135		
2	M 592	20	130		
3	BM 261	22	128		
4	BM 120	27	123		
5	BM 3510	28	122		
6	XXX H 401	29	121		
7	Mel Kraft	30	120		
8	Norton	36	116		
9	Catalin	38	112		
10	Hard rubber	43	107		
11	Styrene	44	106		
12	Lucite	47	103		
13	Vinylite	48	102		
14	CR 39	58	92		
15	XP 208 D	59	91		
16	Laminac	63	87		
17	Lumarith	76	74		
18	Fibestos	88	62		
19	Plastacele	93	57		
20	Saran	137	13		
	Acetate H8	64	86	30	120
	H4	81	69	36	114
	H	105	45	48	102
	MH	103	47	46	104
	M	128	22	58	92
	S2	139	11	62	88
	S4	161		74	76
	S9	142	8	65	85
	PP3 (½-in. bar)[a]			103	47
	Synthetic sole material			148	2

[a] Soft Amino Resin.

Since the makers of the Rockwell tester have exhausted the English alphabet for scale designations, we might start on the Greek and call the above the alpha and beta scales.

A tabulation of the 28 materials would be as shown in Table X.

TABLE XI.

Order	Material Number	Material	Thickness, in.
1	3319	Paper-base melamine laminate	3/16
2	BM261	Mineral-filled phenolic	⅛
3	BM120	Wood-flour-filled phenolic	⅛
4	F3	Polystyrene, Monsanto, injection molded	⅛
5	R3394	Lucite-boilable	⅛
6	II-⅛	Plexiglas type II	⅛
7	XMS 10023	Polystyrene-Bakelite compression molded	¼
8	VS1310	Vinylite clear	⅛
9	R3393	Lucite standard	⅛
10	1A-⅛	Plexiglas type 1A	⅛
11	L01 39	Nylon type FM1	⅛
12	II-¼	Plexiglas type II	¼
13	1A-¼	Plexiglas type 1A	¼
14	CR39	ZS-3364 clear	⅛
15	3414	Laminac clear	¼
16	D1223	Cellulose nitrate—Nitron	⅛
17	3323	Laminac canvas laminate	⅛
18	D1224	Cellulose acetate—Fibestos	⅛
19	22630	Ethyl cellulose—Hard	⅛
20	205A-H2	Cellulose aceto-butyrate	⅛
21	22631	Ethyl cellulose medium hard	⅛
22	Saran 1	Saran compression molded	⅛
23	205A-M	Cellulose aceto-butyrate	⅛
24	Saran B115	Saran injection molded	⅛
25	205A-S2	Cellulose aceto-butyrate	⅛

If we can assume an average factor of 2.17 representing the ratio of observed indentation between the 60- and 30-kg. loads, these scales can be roughly converted as follows

$$\alpha \text{ scale} = 150 - 2.17 \times (150 - \beta \text{ scale hardness})$$

$$\beta \text{ scale} = 150 - \frac{150 - \alpha \text{ scale hardness}}{2.17}$$

Simplifying these expressions gives

$$\alpha = 2.17\beta - 175$$

$$\beta = \frac{175 + \alpha}{2.17}$$

This conversion will give values within 5 scale divisions of the observed values

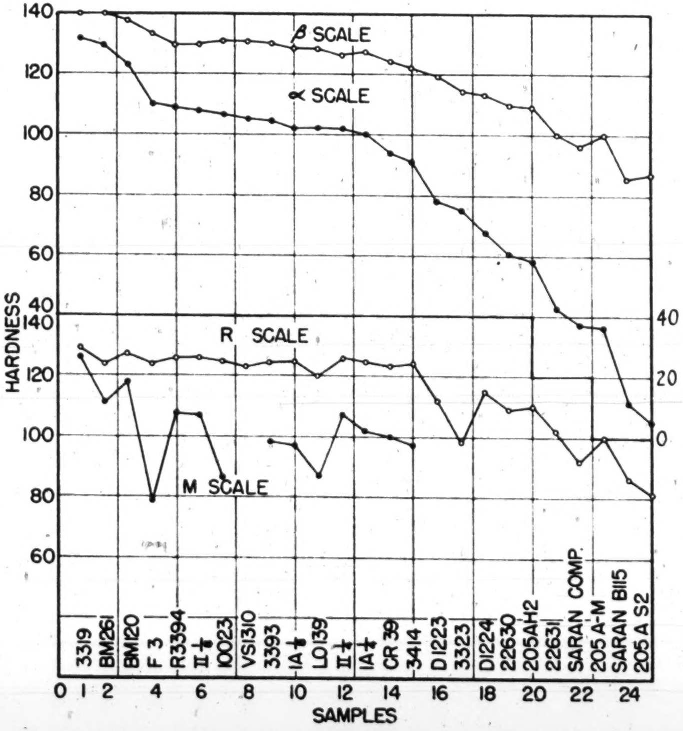


FIG. 10.—Indentation Hardness, α and β Scale, and Rockwell, M and R Scale, of 25 Plastic Samples.

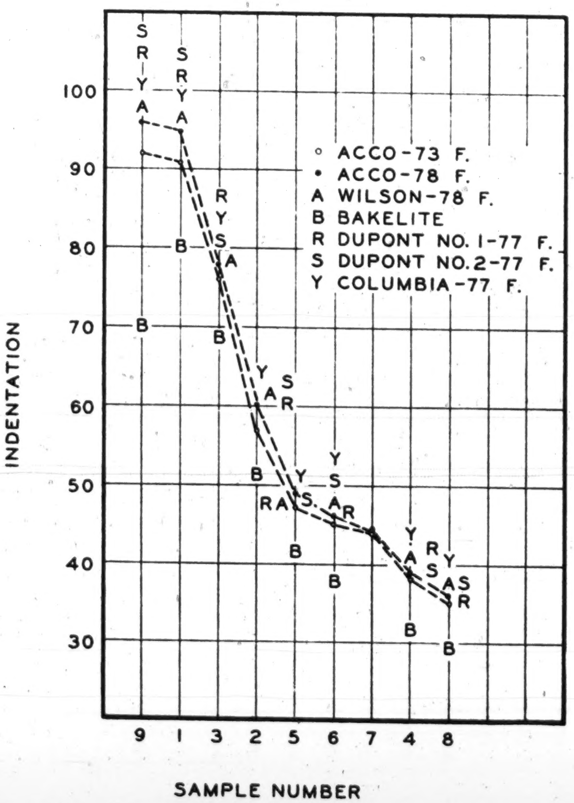


FIG. 11.—Reproducibility of α Scale Indentation.

on the typical samples shown. We cannot emphasize too strongly that this is only a rough conversion and that the average factor of 2.17 is subject to confirmation on each specific type and possibly hardness of material.

An additional group of samples[8] was tested for indentation hardness by the various procedures. The identity of the samples is shown in Table XI. Their hardness by the α and β scales and by the M and R scales is given in Fig. 10. The average factor between observed indentation at 60 and 30 kg., respectively, was 2.16 for this group.

TABLE XII.—SUMMARY OF ROCKWELL INDENTATION UNDER LOAD.

½-in. Ball, 60-kg. Load, 15 sec.

Sample	Material	ACCO		Wilson, 78 F.	Columbia, 77 F.	Du Pont		Bakelite
		73 F.	78 F.			1–77 F.	2–77 F.	
No. 1	Fibestos	91	95	96	97	99	100	80
No. 2	CR39-1	57	60	61	64	61	62	51
No. 3	Lumarith	76	78	78	82	83	80	69
No. 4	Catalin	38	39	41	43	40	40	31
No. 5	Vinylite	47	49	48	51	48	48	41
No. 6	Lucite	45	46	47	51	46	50	38
No. 7	Styrene[a]	44	44	..	..	..	..	..
No. 8	Norton 7-3	35	36	37	40	36	38	39
No. 9	Plastacele	92	96	98	99	105	107	70

[a] Badly warped specimen.

Reproducibility:

A series of nine samples of typical plastic materials[9] was tested by five laboratories, representing six individual Rockwell hardness testers. All samples were conditioned and tested at 77 to 78 F. and 50 per cent relative humidity. These values are shown in Table XII and plotted in Fig. 11. The Bakelite machine, which gave consistently lesser depth of indentation, was an old model in which the frictional losses at low loads were appreciable. Among the other five machines none showed a deviation from the average of more than about 10 per cent. A higher degree of uniformity might be gained by a more careful intercalibration of the instruments.

Effect of Thickness on Indentation:

There is a commonly accepted idea that the indentation observed on a given material is constant as long as a minimum thickness is exceeded and the anvil no longer affects the depth attained by the indenter. To establish the effect of thickness, several representative materials were prepared as follows:

A bar or piece of each material was cut so that the original test surface was undisturbed, but the amount of substance below this surface was varied by machining it to a given thickness. The back of each piece was lapped flat by means of fine abrasive paper.

The Rockwell indentation under load was then measured for each piece, a given value representing an average of three tests. Both flat anvil, and spot anvil (raised spot $\frac{3}{16}$ in. in diameter) were used. The data are shown in Figs. 12 and 13. It is seen that, in general, increase in thickness is accompanied by increase in indentation (up to the limit tested, $\frac{1}{2}$ in.). From $\frac{1}{16}$ in. to $\frac{1}{2}$ in., each material has its own type of curve. The spot anvil invariably shows greater indentation than the flat anvil, because of the obvious effect of indenting on both sides.

Samples $\frac{1}{16}$ in. in thickness showed two extreme types of behavior. One extreme is illustrated by hard rubber, where the indentation is much less than that measured on thicker pieces. The other extreme is shown by several acetates where there appears to be a minimum indentation at about $\frac{1}{8}$ or $\frac{1}{4}$ in. Thicknesses greater or less than this showed greater indentation. In the case of thin pieces of soft plastic

---

[8] Furnished by J. D. Ryan, Libbey-Owens-Ford Glass Co

[9] Furnished by M. E. Marks, Pittsburg Plate Glass Co.

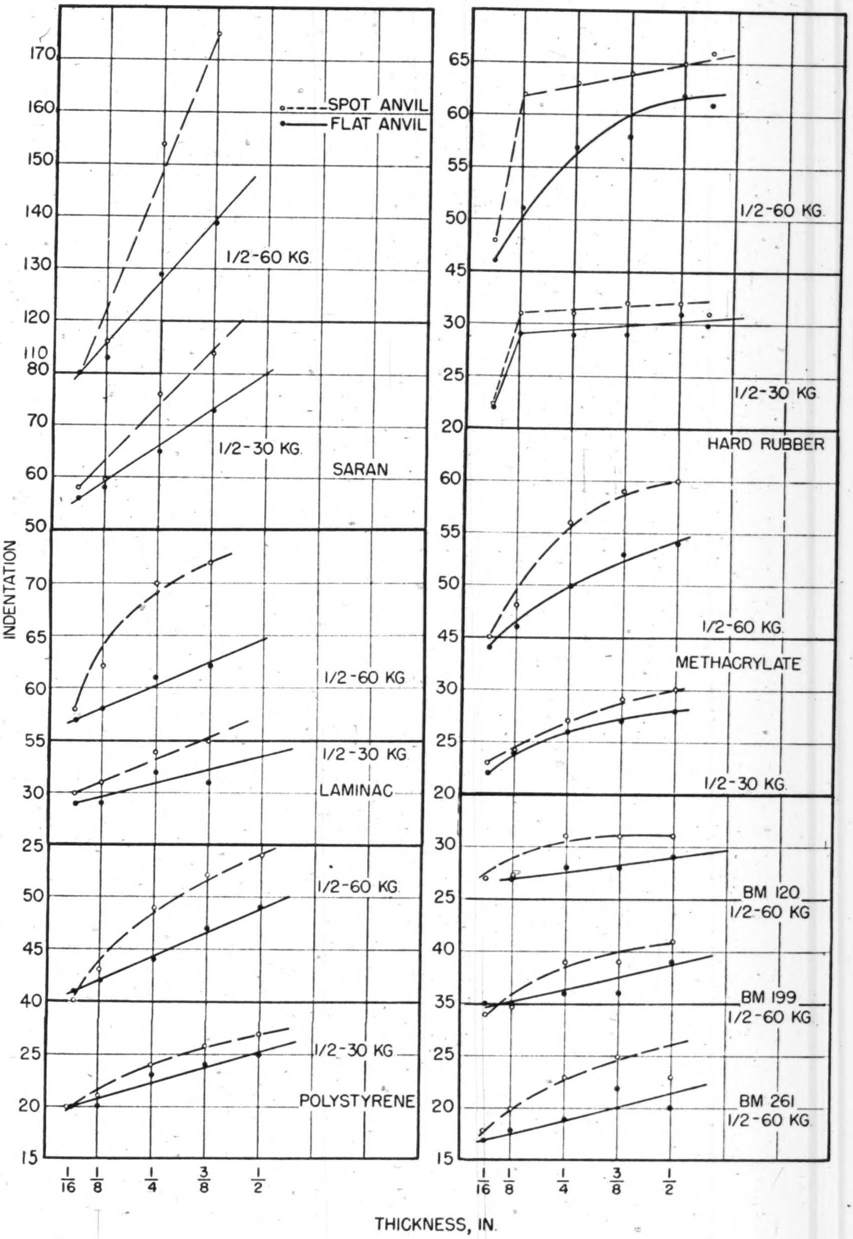


FIG. 12.—Effect of Thickness on Depth of Indentation.

this might be due to a sideward flow of material away from the point of indentation. Other materials show a uniformly steady increase of indentation with thickness. This behavior will probably affect the slope and intercepts of log L, log d curves shown in Figs. 8 and 9 and also the factor relating the indentation between 60- and 30-kg. loads. For such studies, thickness must be either kept uniform, or its effect must be determined.

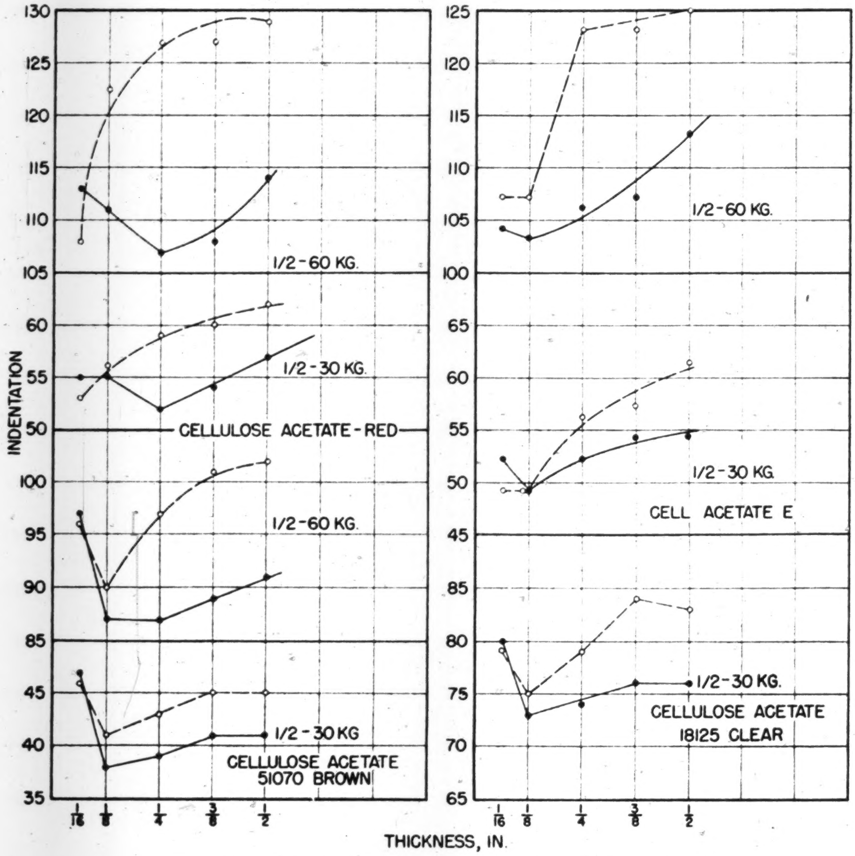


FIG. 13.—Effect of Thickness on Depth of Indentation.

Another commonly used procedure is to stack several layers of thin sheet material to form a total minimum test thickness. During the investigation of this procedure on indentation, another important factor became evident. Many test materials, especially those prepared by molding, have faces which are not perfectly flat, due to crowning of top and bottom plungers of the mold or to warpage after removal from the mold. If such a piece is tested with the concave side down on the flat anvil, obviously the piece will be resting only on the edges, and if it does not bend sufficiently to bring the center into contact with the anvil when the minor load is applied, this gap will be closed when the major load is applied and will register on the dial gage as indentation. A gap of 0.001 in. corresponds to 12 scale divisions. The tests shown in Table XIII were made on 2-in. disks, ⅛-in. thick, of BM 120 black, which had parallel faces, but one side was about 0.015 in. convex and the other was correspondingly concave.

It is clear that in a single thickness, the minor load has closed the gap present with the concave side down, and the same indentation is obtained as in the reverse direction. With two layers bridged across the anvil, the minor load does not close the gap and this amount is observed as extra depth of indentation.

TABLE XIII.

BM 120 tested singly:	Indentation, ½-in. Ball, 60-kg. Load
Concave up—Piece No. 1	28
No. 2	28
No. 3	27
Concave down No. 1	28
No. 2	28
No. 3	29
2 pieces both concave up—Nos. 1 and 2	30
Nos. 2 and 3	31
Nos. 3 and 1	31
2 pieces both concave down—Nos. 1 and 2	45
Nos. 2 and 3	56
Nos. 3 and 1	48
3 pieces all concave up—Nos. 1, 2, 3	33
3 pieces all concave down—Nos. 1, 2, 3	68
No. 1 top, concave down No. 2 concave up No. 3 concave down	53

It is therefore of utmost importance that the bottom surface of a test specimen is flat or slightly concave. This effect is particularly troublesome in thick pieces which may have local concave areas, smaller than the diameter of the flat anvil. These must be lapped to a flat or slightly concave bottom surface before testing. To observe the effect of layering of flat, parallel pieces on indentation, the following materials were prepared:

BM 120,[10] ⅛-in. molded disks were lapped flat on both sides. An original molded surface was tested as the top piece.

Paperbase phenolic laminates,[11] XXX H 401 and XP 208 D, ⅛ in. thick, were cut into 1-in. squares, and the edges were carefully rounded to remove saw burrs.

Successive layers were then tested for indentation with the ½-in. ball and 60-kg. load. The values in Table XIV were obtained, and they are plotted in Fig. 14.

Comparing, first, the values obtained on BM 120, for solid samples of various thicknesses with the same material in the form of ⅛-in. layers of equivalent thickness, it is seen that indentation changes with thickness at different rates. On ⅛-in. thick layers of typical laminates the rate of change of indentation with increasing layers is even more marked, and is specific for each type of structure.

TABLE XIV.

Layers	Total Thickness, in.	Indentation Under Load		
		BM 120	XXX H 401	XP 208 D
1	⅛	28	31	56
2	¼	30	36	64
3	⅜	33	39	72
4	½	34	40	75
5	⅝	36	41	77
6	¾	38	43	79
7	⅞	39	44	82
8	1	40	46	83
Solid bar	½	29		

It is evident that any hardness value, based on indentation under load, will be, to some extent, a function of thickness, and also of the number of layers making up this thickness. The above described behavior should be considered in any hardness testing procedure.

---

[10] Samples from W. A. Zinzow, Bakelite Corp.

[11] Samples from G. H. Mains, National Vulcanized Fibre Co.

UTILITY OF HARDNESS TESTS

The question frequently arises, "Of what use is hardness testing?"

This can be answered only by the workers in each particular field of plastics. This paper has been an attempt to clarify some of the factors involved and to indicate limitations. Certainly we are not yet in a position to relate hardness to other properties with any degree of exactness.

The test may be used as a quick nondestructive test of identity. It will indicate roughly the compressive (and perhaps tensile) modulus. By the use of the more elaborate analysis, some indication of progressive polymerization in reactive resins may be obtained, and the effect of various fillers and plasticizers may be followed.

In conclusion we wish to express our thanks to the Directors of the Stamford Laboratory for permission to publish this paper, to the staff for their assistance and suggestions, to Mr. V. E. Lysaght of the Wilson Mechanical Instrument Co. for his valuable aid, and to the members of Subcommittee II on Hardness Properties of A.S.T.M. Committee D-20 on Plastics for their contributions in the form of samples and cooperative tests.

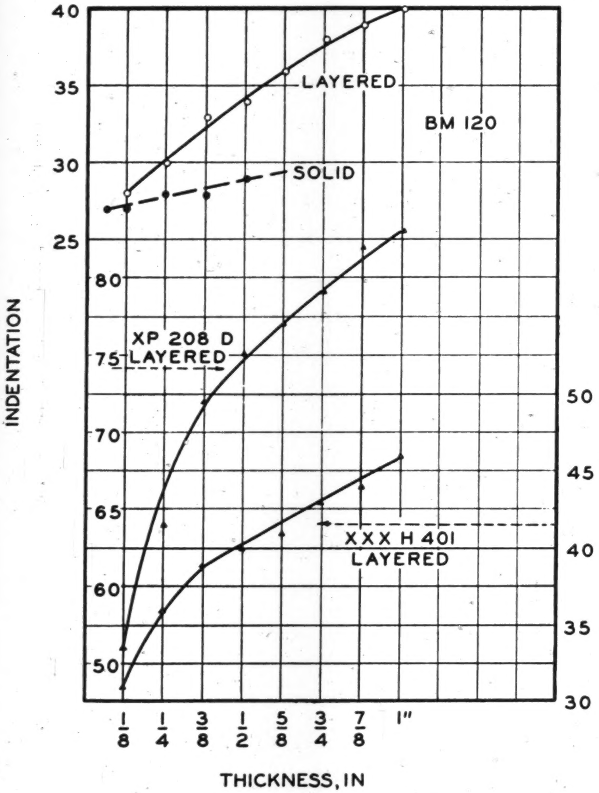


FIG. 14.—Effect of Layering on Depth of Indentation.

REFERENCES

(1) David Starkie, "The Hardness and Scratch Resistance of Plastics," *Journal*, Soc. Glass Technology, Vol. 26, June, 1942, pp. 130–144.

(2) G. M. Kline and B. M. Axilrod, "Study of Transparent Plastics for Use on Aircraft," RP 1031, *Journal of Research*, Nat. Bureau Standards, Vol. 19, October, 1937, pp. 367–400.

(3) A. H. Pfund, "Tests for Hardness, Gloss, Color, and Leveling of Varnishes," *Proceedings*, Am. Soc. Testing Mats., Vol. 25, Part II, p. 392 (1925).

(4) G. O. Conabere, "Firmness, Compressibility and Abrasion Resistance of Sole Leather," *Journal*, Int. Soc. Leather Trades' Chemists, Vol. 28, February, 1944, p. 25.

(5) Robert H. Heyer, "Analysis of the Brinell Hardness Test," *Proceedings*, Am. Soc. Testing Mats., Vol. 37, Part II, p. 119 (1937).

(6) S. R. Williams, "Hardness and Hardness Measurement," Am. Soc. Metals, p. 281 (1942).

DISCUSSION

Mr. Vincent E. Lysaght[1] (*presented in written form*).—Mr. Boor has made an exceptionally careful analysis of the use of the Rockwell Tester for measuring the hardness of plastics and has also considered the subject of the value of a hardness test on plastic material.

The important contribution of this paper is that the author has taken a machine already on the market and used by thousands of companies for metal testing, for which it was designed, and adapted it to the problem of testing plastics. The method may be involved and complicated, but if this test is the one which will furnish the necessary information to those interested in studying the hardness of plastics, it is possible that changes in the design of the tester can be made so as to simplify making this test.

Up to this time, it has been very difficult for the manufacturers of hardness testing equipment to know just what type of test is desired by the manufacturers and users of plastic material, and with this fundamental requirement lacking, it was impossible for any instrument company to design a machine for testing plastics. With the information given in this paper, it is possible for the plastic industry to determine whether this test is the one they desire and, if so, the problem of providing a simpler machine or modifications of the present machine, can be studied.

Mr. Ladislav Boor[2] (*author's closure, by letter*).—Since the presentation of this paper, the author has been informed of some tests utilizing the Rockwell instrument with $\frac{3}{4}$-in. indentor and 100-kg. and 60-kg. loads. The 100-kg. load produced indentations near the practical limit of the machine on the softer plastics. The 60-kg. load gave readable differences of indentation under load. In both cases, the rank of seven samples by depth of indentation under major load was entirely different from that obtained by observing the depth of indentation after major load was removed.

Evidence of a growing recognition of the behavior of plastics under loaded indentors is a method in use by the automotive trade which records hardness indices under both major and minor loads.

The range of resistance to indentation of commercial plastics, from mineral filled thermosetting materials to the softer thermoplastics is enormous, and a method including them all on a single scale will inevitably lack the precision to separate closely similar materials.

We hope that this paper and discussion will serve to stimulate interest in this field, and to encourage further investigation of indentation relationships.

---

[1] Assistant to the President, Wilson Mechanical Instrument Co., Inc., New York, N. Y.

[2] Physics Division, American Cyanamid Co., Stamford Research Laboratories, Stamford, Conn.

IMPACT TESTING OF PLASTICS—II. FACTORS WHICH INFLUENCE THE ENERGY ABSORBED BY THE SPECIMEN

By David Telfair[1] and H. K. Nason[1]

Synopsis

The energy required to fracture a specimen is discussed from the standpoint of its dependence on the following four factors:

1. Dimensions of the test specimen,
2. The notch,
3. Rate of stressing, and
4. Temperature.

These factors are first considered briefly from a theoretical standpoint. Some of the similarities and some of the differences in the behavior of the plastics on the one hand, and of metals on the other, are brought out.

A series of experimental results are discussed and are shown to be in general agreement with the theoretical approach. As with metals, it appears that the state of stress (as influenced by the notch) plays a more dominate rôle in determining the behavior of plastics than does the speed of testing or the temperature.

For those plastics which exhibit very little ductile behavior, the energy absorbed in fracturing an unnotched specimen loaded as a simple beam is shown to be consistent with an equation derived from the theory of elasticity.

Experimental evidence is presented which indicates that for many plastics the tensile strength varies linearly with the logarithm of the stressing rate over a relatively wide range.

In an earlier paper (**1**)[2] the authors discussed certain disadvantages of the standard pendulum type Izod and Charpy impact test methods. In particular, it was shown that the energy measured by these tests often obscures the true impact resistance of a material by including the energy absorbed in tearing apart and throwing the broken ends. Only that portion of the energy used in fracturing the specimen is of practical significance. Several authors have discussed revised impact machines and test methods (**1, 2, 3, 4, 5, 6**) which are designed to measure only the energy to fracture. Such methods and machines are necessary prerequisites to any attempt to correlate impact strength with other properties, or to interpret impact test results in terms of more fundamental properties of a material. As a number of authors have pointed out, however, (**7, 8, 9, 10, 11, 12, 13**) there exist several complicating factors, the most important of which are those listed above in the synopsis. It will be the purpose of this paper to discuss these factors as they apply to the impact testing of plastics. It is hoped that such a discussion will help to clarify many of the problems involved and will throw light on the possibilities of the impact test as a means of revealing the physical properties of plastic materials.

---

[1] In charge of Physical Testing and Assistant Director of Research, respectively, Plastics Division, Monsanto Chemical Co., Springfield, Mass.

[2] The boldface numbers in parentheses refer to the reports and papers appearing in the list of references appended to this paper, see p. 1004.

THEORETICAL

Fundamental Considerations:

Impact strength, in its usual sense, might be defined as the energy absorbed in the process of deforming a standard specimen to the point of rupture. This energy must be supplied by externally loading the specimen and thereby building up internal stresses which eventually result in failure at some localized point. The energy absorbed in the internal stressing is equal to the external work done by the applied load:

$$W = \int_0^S p\,ds \,\ldots\ldots\ldots (1)$$

where:

$W =$ the external work done,
$p =$ the applied load,
$s =$ the distance through which the load p has moved, and
$S =$ the value of this distance at the point of failure.

If the deformation follows Hooke's law, that is, if $p = ks$, then Eq. 1 integrates to:

$$W = \frac{PS}{2} \,\ldots\ldots\ldots\ldots (2)$$

where $P =$ the value of p at the point of failure. In the general case, where Hooke's law is not obeyed, the integral (Eq. 1) may be evaluated by measuring the area under the load *versus* deformation curve with a planimeter.

Thus it is seen that both force and the distance through which the force moves are involved in determining impact strength. Alternatively, this may be stated by saying that both the strength and the ability of a material to deform under load are involved.

It is known from experiment that, under proper stress conditions, extremely brittle materials such as marble or cast iron will exhibit a surprisingly high degree of ductile deformation. On the other hand, even the most ductile of metals can be made to fail in a brittle fashion when they are subjected to certain other conditions of stress. To a fair degree of approximation the stress conditions which determine whether a failure will be ductile or brittle may be described in terms $\sigma_{\text{max.}}$ and $\tau_{\text{max.}}$, the maximum tensile and maximum shearing stress, respectively. In all materials, plastic or ductile deformation takes place under the action of shearing stress, after the latter has reached a certain critical value. Likewise, a material fractures only when the tensile stress reaches a critical value. If $\sigma_{\text{max.}}$ reaches its critical value before $\tau_{\text{max.}}$ reaches the value at which yielding takes place, then brittle fracture occurs.[3] Otherwise, the material will deform ductilly until, under the action of strain hardening, the critical values of tensile and shearing stress are changed so as to result in failure.

The effect of a notch in producing brittle failure may be best described in terms of the above approach. Around the base of the notch there exists a state of stress corresponding to a high value of $\sigma_{\text{max.}}$, and a low value of $\tau_{\text{max.}}$. The possibility of ductile deformation is thereby greatly lowered, and brittle failure, or diminished ductility results.

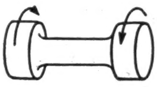
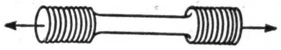
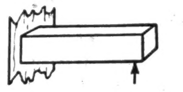
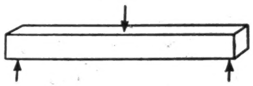
Different types of impact specimens, for example, tension, torsion, or flexed beams, will have different ratios of maximum shearing to maximum tensile stress, and consequently one specimen may give a ductile failure and show a high impact strength, whereas another of the same material will result in a brittle failure and a low impact strength.

---

[3] This interpretation has been verified experimentally for transparent Bakelites (BT-61-893 and BT-46-001) by photoelastic stress analysis. See M. M. Frocht, *Journal Applied Mechanics*, Am. Soc. Mech. Engrs., Vol. 3, No. 3, p. A-99 (1936).

If we are concerned with materials which exhibit a brittle failure under conditions of tensile, flexural, or even torsional loading, such as many plastics, then the impact strength is not complicated by the question of ductility. In such cases we may use Eq. 2 for describing the energy stored in the test specimen. The classical theory of elasticity allows us to express the maximum load, p, and the maximum deflection, or distance through which the load moves, S, in the terms of (1) the dimensions of the specimen, (2) the critical stress or stress at which failure takes place, and (3) the moduli of elasticity of the material.[4] Table I gives expressions for the energy derived in this way for several possible test specimens. A comparison of the equation for the simple unnotched beam with experiment will be made later in this paper.

TABLE I.—CHARACTERISTICS OF VARIOUS TEST SPECIMENS.

Specimen Type	Description of Stress	Opportunity for Ductile Deformation	Dependence of Energy on Dimensions
 Torsion	Non-Uniform $\frac{\sigma_m}{\tau_m} = 1$	Good	$W_E = \frac{1}{4} V \frac{\tau_m^2}{G}$ (Eq. 3) $W_P = ?$
 Tension	Uniform $\frac{\sigma_m}{\tau_m} = 2$	Fair	$W_{\text{Total}} = KV$ (Eq. 4) K = Area Under Stress — Strain Curve.
 Cantilever Beam, Unnotched	Non-Uniform $\frac{\sigma_m}{\tau_m} \begin{cases} = 2, \text{ Unnotched} \\ > 2, \text{ Notched} \end{cases}$	Somewhat Less Than for Tension	$W_E = \frac{1}{18} V \frac{\sigma_m^2}{E} \left(1 + \frac{3E}{10G} \frac{D^2}{L^2}\right)$ (Eq. 5) $W_P = ?$
 Simple Beam, Unnotched, Centrally Loaded	Non-Uniform $\frac{\sigma_m}{\tau_m} \begin{cases} = 2, \text{ Unnotched} \\ > 2, \text{ Notched} \end{cases}$	Somewhat Less Than for Tension	$W_E = \frac{1}{18} V \frac{\sigma_m^2}{E} \left(1 + \frac{6E}{5G} \frac{D^2}{L^2}\right)$ (Eq. 6) $W_P = ?$

It should be clearly understood that these equations can be expected to be good approximations only (1) for unnotched specimens, (2) when values of maximum stresses and moduli corresponding to the speed and temperatures of testing are used, and (3) for cases of brittle fracture, or where the load *versus* deformation curve is approximately a straight line.

---

[4] Analyses of this kind may be found in S. Timoshenko's "Strength of Materials," D. Van Nostrand Co., New York, N. Y., Vol I, pp. 173 and 296 (1940).

The effect of a notch will always be such as to complicate the distribution of stress in the specimen in such a way that a mathematical analysis becomes very difficult, or impractical. If the material is a typically brittle one, the impact strength is lowered because of the stress-concentrating action of the notch. The chances are, however, that this lowering of impact strength will not be as pronounced as it is for a typically ductile material, if the notch sufficiently inhibits plastic deformation to result in brittle failure.

Rate of Stressing:

Perhaps the most outstanding difference between plastics and metals is the greater dependence of the former upon the time factor. In general it is not possible to consider strain of plastics as a function of stress alone, as in the case of metals at room temperature. For plastics, strain becomes a function of stress and of *time*. They must be considered as visco-elastic materials rather than as elastic materials. One of the manifestations of this time-dependent character of plastics is their relatively large creep under steady load (**14**). Another is their high capacity for damping out mechanical vibrations (**15**, **16**).

There is a common concept to the effect that, as the speed of loading increases, the impact strength of a material decreases. Actually, the reverse is more nearly consistent with experiment, both for plastics and for metals. The confusion seems to arise primarily because unnotched specimens are usually used for static testing whereas notched specimens are used for impact testing.

The notch nearly always dominates the behavior of the specimen and is usually responsible, rather than is the increase in speed, for a decrease in energy to fracture. In the special case where conditions are such that $\sigma_{max.}$ and $\tau_{max.}$ reach their critical values nearly simultaneously, only slight changes in the notch, the temperature, the size and shape of the specimen, or the internal structure of the material may result in a transition from ductile to brittle failure, or *vice versa*. It is in or near this critical transition region that changes in loading speed will have the greatest effect on impact strength. Ductile-brittle transitions have been observed in metals by varying speed alone, and many plastics would undoubtedly show a similar behavior. The closely related phenomenon of raising the yield point by increasing stressing rate is easily observed for such plastics as cellulose acetate and cellulose nitrate in tension. It is reasonable to assume that as the stressing rate is increased more and more for these materials that eventually a point will be reached at which the yield stress (or critical shearing stress) is equal to or exceeds the cohesive strength (or critical tensile stress). For speeds above this critical speed brittle failure would be produced. However, it appears that the cohesive strength of normally ductile plastics increases with speed about as rapidly as does the yield point. Thus the impact strength change may be relatively small for large changes in testing speed. A doubling of impact strength frequently corresponds to an increase in speed of several hundred or thousandfold.

Effect of Temperature:

The strength of plastics is, in general, considerably more sensitive to temperature changes than is that of metals. Accompanying their change in strength with temperature, a change in ductility or in ability to deform for a given stress ratio, $\sigma_{max.}/\tau_{max.}$ may be expected. Also, the dependence of deformation on time is known to change considerably with temperature (**14**). The change of each of these variables, (strength, ductility, and creep or speed characteristics) with temperature will have its effect on impact strength.

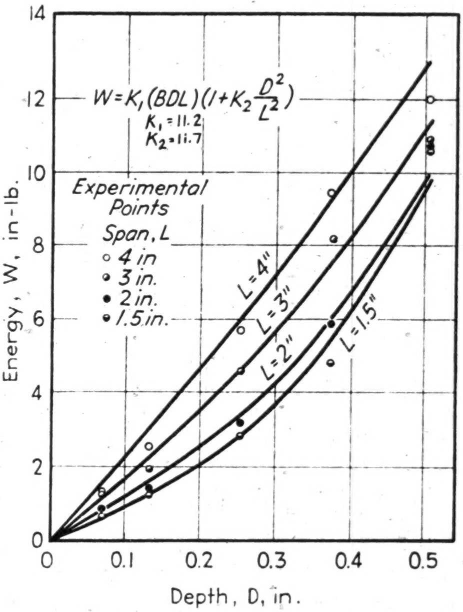


FIG. 1.—Theoretical Expression for the Energy Required to Fracture an Unnotched, Simply-Loaded Beam with the Constants, K_1 and K_2, Chosen so as to Fit Experimental Points for Four Different Spans. (Experimental Data Supplied by H. E. Marks).

EXPERIMENTAL

Dependence of Impact Energy on Dimensions:

As already indicated, a large and important branch of the plastics family,

TABLE II.—EXPERIMENTAL AND CALCULATED VALUES FOR THE ENERGY REQUIRED TO FRACTURE AN UNNOTCHED BEAM IN SIMPLE THREE-POINT LOADING.

Material	Energy to Fracture Unnotched Specimen, ft-lb.		
	Calculated from Eq. 6 of Table I	Experimental—Area Under P vs. δ Curve	Experimental—Unnotched Charpy. (Higher Speed)
Woodflour filled phenolic, machined face in tension	0.178	0.168±0.018	0.265±0.031
Asbestos filled phenolic, machined face in tension	0.100	0.107±0.015	0.231±0.024
Woodflour filled phenolic, molded face in tension	0.307	0.300±0.053	......
Asbestos filled phenolic, molded face in tension	0.190	0.158±0.020	......

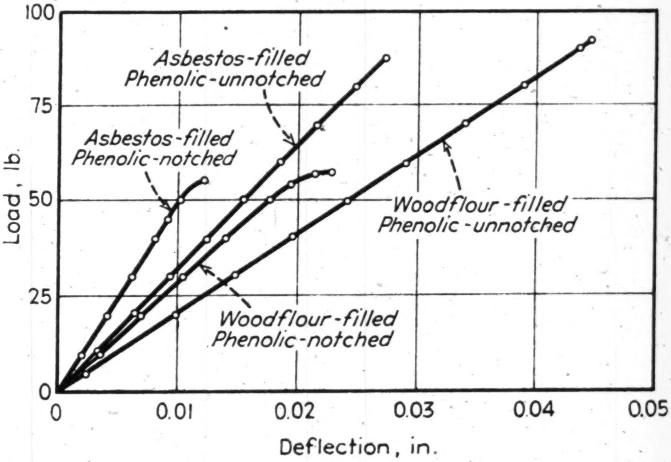


FIG. 2.—Flexural Load-Deflection Curves for two Phenolic Materials. (Notched Samples had a Depth of 0.5 in., with 0.4 in. below the Notch. Unnotched Specimens Had a Uniform Depth of 0.4 in.)

namely, the thermosetting plastics, fail with little or no ductile deformation. For ordinary rates of loading, their stress-strain curves and load-deflection curves are essentially straight lines all the way out to the point of failure (see Fig. 2). This fact, coupled with the fact that their total strain at failure is small, makes it possible to describe their impact strength, or the energy absorbed in deforming them up to the point of initial fracture, by means of the equations given in Table I. In applying these equations, however, it must be remembered that the tensile strength and moduli values may be considerably higher at high rates of loading, such as encountered in impact, than they are for the loading rates used in static tests.

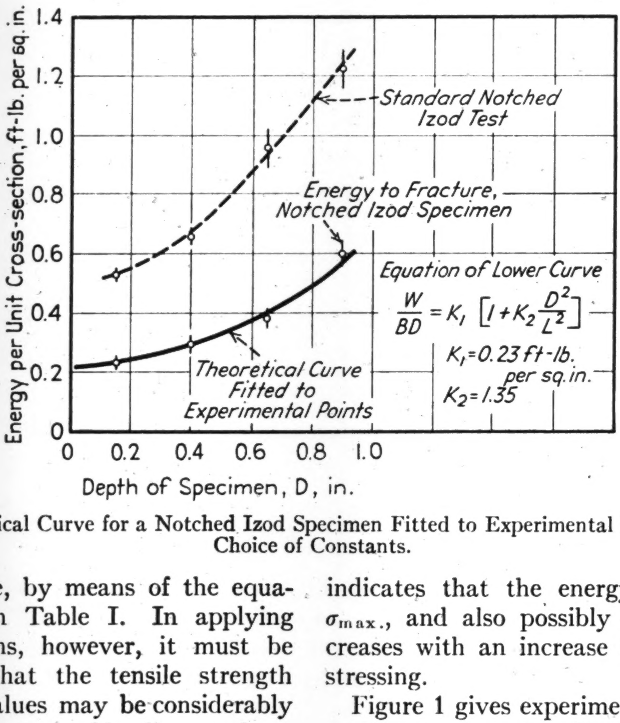


FIG. 3.—Theoretical Curve for a Notched Izod Specimen Fitted to Experimental Points by Proper Choice of Constants.

Table II presents data for the energy to fracture calculated by means of Eq. 6 of Table I from experimentally determined values of $\sigma_{\text{max.}}$, E, and G. For comparison, values are listed for the energy determined experimentally from the area under the load-deflection curve of each material. In the first two cases, data were also available for unnotched Charpy impact values. The rate of stressing in the Charpy impact test was approximately 30,000 times as rapid as in the static flexural test from which the data in the second column were obtained. The agreement between columns 1 and 2 reflects the fact that the constants used for calculating the theoretical value ($\sigma_{\text{max.}}$, E, and G) were those obtained from static tests. More experimental evidence will be given below under the heading "Rate of Stressing," which indicates that the energy to fracture, $\sigma_{\text{max.}}$, and also possibly E and G, increases with an increase in the rate of stressing.

Figure 1 gives experimental points for specimens of varying dimensions of C.R. 39 resin obtained by M. E. Marks of the Columbia Chemical Div. of Pittsburgh Plate Glass Co. These points are seen to be in general agreement with the four theoretical curves, which represent Eq. 6 for each of the four different values of span used.[5]

---

[5] Since the writing of this paper, Mr. Marks has presented further data on this subject before Subcommittee VIII on Research of A.S.T.M. Committee D-20 on Plastics (New York, June 27, 1944). His data are further evidence of the suitability of an equation of the same form as Eq. 6 for describing the dependence of impact strength on dimensions for unnotched specimens.

The Notch:

Figure 4 shows the surprisingly large reduction in energy-to-fracture which is produced by a standard A.S.T.M. notch in Izod specimens.[6] It is apparent that for some of these materials, very little elastic strain energy can be stored throughout the volume of the specimen before the stress in the localized region below the notch has increased sufficiently to result in fracture.

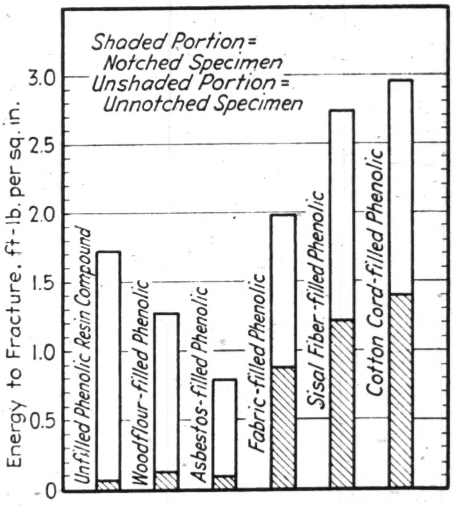


FIG. 4.—Comparison of the Energy to Fracture a Notched Specimen (Shaded Portion) with that Required to Fracture an Unnotched Specimen (Total Height).

The authors have evidence that the variation of energy-to-fracture with the dimensions of notch specimens may be described by an equation of the same form as Eq. 6 but with different constants (see Fig. 3). However, it is unlikely that such an equation would remain valid as dimensions are varied over a relatively wide range.

Fibrous Fillers:

The incorporation of fibrous fillers in brittle resins has the desirable effect of reducing the notch sensitivity. As shown in Fig. 4, the energy required to initiate a crack at the base of the notch is considerably greater for fibrous filled materials than for non-fibrous fillers, or for unfilled resins. This effect is again illustrated in terms of the load in flexure required to initiate a crack at the base of the notch, by comparing the loads at failure as given by Fig. 2 (nonfibrous fillers) and Fig. 5 (fibrous fillers). Figure 5 also shows how, after the crack has been initiated, the load does not fall to zero as in the case of nonfibrous fillers, but falls off more or less gradually, as the broken ends are torn apart.

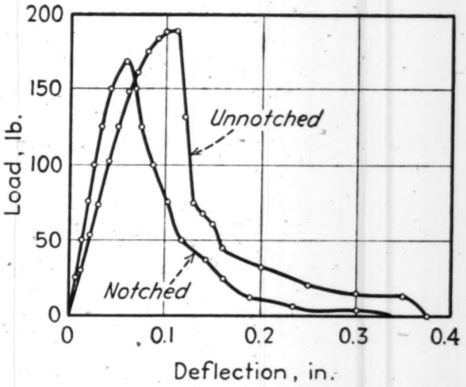


FIG. 5.—Flexural Load-Deflection Curves for Notched and Unnotched Specimens of a Fabric Filled Phenolic Molding Material.

Judging from these effects, the fibers have the ability to distribute the stress at the base of the notch over a greater volume, thereby reducing its peak value. Thus, a greater load is required to produce a crack. After the crack is produced, the fibers apparently block the propagation of the crack by allowing a portion of the stress to be carried by fibers above the advancing edge of the crack. Thus the load continues to rise (in the notched flexural test) after a crack has been initiated, and the load decreases in a series of sudden breaks as the crack is propagated across the fibrous filled specimen. In contrast to this, the inception of the first crack results in complete failure for materials without fibrous fillers.

---

[6] Tentative Methods of Test for Impact Resistance of Plastics and Electrical Insulating Materials (D 256 - 43 T), 1943 Supplement to Book of A.S.T.M. Standards, Part III, p. 249.

TABLE III.—EFFECT OF DIFFERENT NOTCHING APPARATUS AND TECHNIQUE ON THE IZOD IMPACT STRENGTH OF A CELLULOSE ACETATE AND A PHENOLIC MATERIAL.

Company Notched by	Sheeted Cellulose Acetate, ft-lb. per in. of notch	Compression Molded Wood Flour Filled Phenolic, ft-lb. per in. of notch
A	1.28 ± 0.30	0.271 ± 0.009
B	1.30 ± 0.19	0.259 ± 0.012
C	1.35 ± 0.13	0.268 ± 0.012
D	1.44 ± 0.23	0.263 ± 0.018
E	1.64 ± 0.09	0.262 ± 0.008
F	1.69 ± 0.12	0.266 ± 0.013
G	1.68 ± 0.27	0.270 ± 0.012
H	1.73 ± 0.34	0.269 ± 0.010
I	1.89 ± 0.23	0.266 ± 0.010
J	1.92 ± 0.12	0.276 ± 0.011
K	2.05 ± 0.26	0.268 ± 0.010
L	2.11 ± 0.09	0.265 ± 0.010
M	2.24 ± 0.15	0.287 ± 0.022

NOTE.—19 specimens were averaged for each value given. The plus and minus limits are the average deviations.

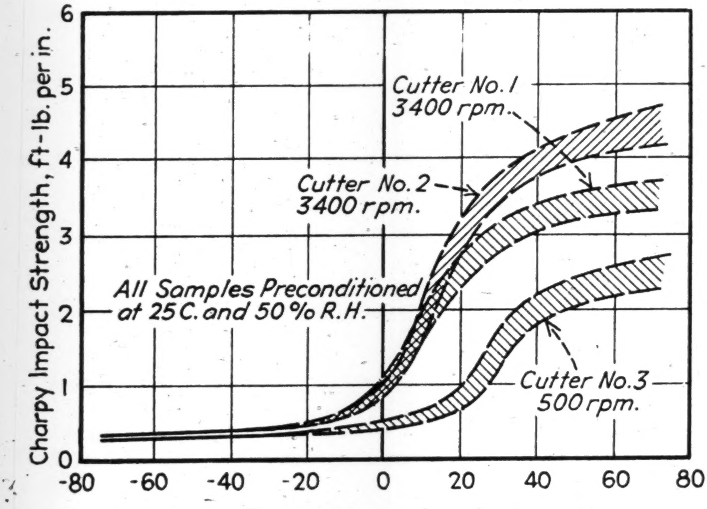


FIG. 6.—Charpy Impact Strength of Cellulose Acetate Versus Temperature, Including the Effect of Using Different Notching Cutters.

Notching Technique:

When one considers the action of the notch in localizing, or concentrating stress, and in imposing a state of stress which inhibits plastic deformation, it is not surprising that the method or technique used in notching is of importance. Table III illustrates the effect of different notching techniques on the A.S.T.M. Izod impact strength[6] of two materials, a molded wood-flour filled phenolic, and a sheeted cellulose acetate plastic. Twelve plastics testing laboratories participated in the notching of these materials, each notching 19 specimens of each material accordingto their usual methods and techniques of producing a "standard" notch. Considerable variation in notch radius and angle, and in general appearance of the notch resulted. The large differences obtained for the cellulose acetate may be associated with the fact that the latter is normally a ductile material, but notched specimens are apparently in a ductile-to-brittle transition region at approximately room temperature (see Fig. 6). Besides using a cutter with the specified angle and radius (45 deg. and 0.010 in.), it appears to be very important that the cutting edge is sharp and free from nicks or irregularities of any kind. The sharpness of the cutting edge is especially important in the notching of ductile plastics, such as cellulose acetate, where a dull or blunt edge produces strain hardening of the material around the base of the notch. Thus its critical shearing stress, or yield point, is raised and it behaves somewhat as would a brittle surface layer, allowing a crack to start more readily.

Rate of Stressing:

In our opinion there exists a definite need for more data on the effect of rate of stressing. The limited amount of data which are available at present indicates that all plastics are essentially visco-elastic materials and as such are more or less sensitive to changes in the rate of stressing. On the low rate end of the scale, data on long-time tensile strength and on creep under constant load indicate that extremely low rates of stressing may result in tensile strengths in some instances of less than one-third of the value obtained in standard tests which are run at a stressing rate of approximately 2000 psi. per min.

Figure 7 gives the relationship between tensile strength and rate of stressing in tension. The two points located between stress rates of 10^{-2} and 10^{-1} psi. per min. were estimated roughly from long-time tensile strength measurements. The point corresponding to a stressing rate of nearly 10^8 psi. per min. was calculated from the measured value of the energy absorbed in breaking an unnotched Charpy impact specimen by using the equation given above. The value calculated was actually maximum fiber stress in flexure, but because data for specimens with machined surfaces were used, the maximum fiber stress was very nearly the same as the tensile strength.[7]

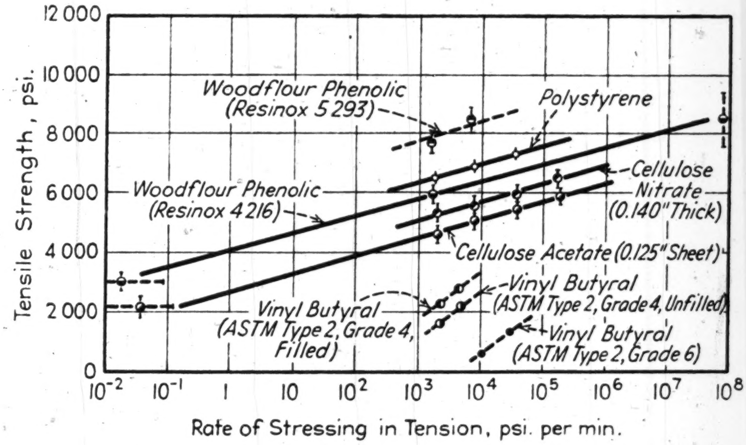


FIG. 7—Effect of Stressing Rate on the Tensile Strength of Various Plastics.

All points lying in the 10^3 to 10^6 psi. per min. range, except those for the vinyl butyrals, were obtained on a Tinius Olsen Universal testing machine, 10,000 lb. range, by testing at the various fixed speeds available. The two upper points, for Resinox 5293, a woodflour filler phenolic, have larger limits of uncertainty than do the remaining points.

---

[7] Experimentally, the maximum fiber stress for machined surfaces and for tensile strength are approximately the same for normal rates of stressing, and there is no obvious reason why they should not also be for high speeds.

The parallelisms of the lines representing three distinctly different plastic materials—wood filled phenolic, polystyrene, and the cellulose plastics—is surprising. Each of these lines may be expressed by an equation of the form:

$$\sigma_{\text{max.}} = K_1 \log\left(\frac{d\sigma}{dt}\right) + \sigma_0 \ldots (7)$$

where:

$\sigma_{\text{max.}}$ = the tensile strength,

$\frac{d\sigma}{dt}$ = the rate of stressing,

σ_0 = a constant, characteristic of the material, and

K_1 = the slope—approximately the same for all of these materials.

The experimental points for the polyvinyl butyral plastics indicate that their tensile strength is much more sensitive to changes in speed than is that of the other plastics investigated.

Intuitively, one would expect the slopes of these curves to "level off" or approach zero both for extremely low and extremely high speeds. Indeed, the data for the polyvinyl butyrals indicate that they would have zero tensile strength for stressing rates somewhere between 10 and 10^4 psi. per min., unless the curves decrease in slope at lower rates. Further experimental work along this line will be very interesting.

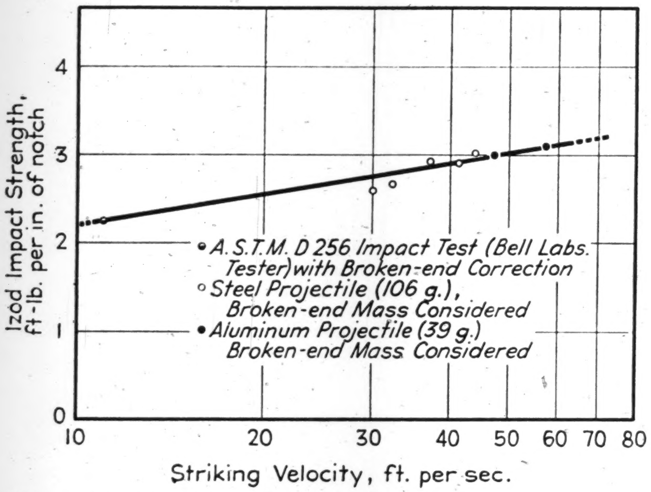


FIG. 8.—Effect of Striking Velocity on the Izod Impact Strength of a Fabric Filled Phenolic Molding Material.

Figure 8 shows the notched Izod impact strength of a fabric-filled phenolic plotted against impact speed on semilog coordinates. The speed of the striking piece just before contacting the specimen is plotted in each case. The low-speed point was obtained by using the A.S.T.M. test method[6] and a standard pendulum impact machine. The remaining points were obtained with a compressed-air gun which fired a blunt nosed projectile at a standard notched Izod specimen. A ballistic pendulum was used for measuring projectile speeds and energy absorption. Because of the relatively high scatter of the high velocity points, it is difficult to draw conclusions as to any definite relationship between impact strength and speed, except that increased speed results in increased impact strength up to velocities as high as 60 ft. per sec. Assuming that the relationship is of the form of Eq. 7, it is seen that the K_1 value (or slope) must be considerably greater in this case. The presence of the notch probably results in greater sensitivity to changes in speed, and may thus be responsible for the greater slope.

Temperature:

Considerable data on the dependence of the impact strength on temperature have already appeared (**17, 18, 19, 20, 21, 29**). In general, the impact strength of the more brittle thermosetting materials varies only slightly over a considerable range of temperatures. The thermosetting resins containing fibrous fillers tend to increase in impact strength up to a critical temperature (usually from 150 to 200 C.) after which they drop off rapidly.

The effect of heat aging is of importance for many plastics. After being subjected to a temperature as low as 135 C. for a period of several hundred hours, the impact strength of most of the organic filled thermosetting plastics begins to drop considerably. Inorganic fillers show no appreciable breakdown for temperatures below about 200 C. For specific information on the effects of continued heating on impact strength of phenolic materials, the reader is referred to an earlier paper (**23**).

Most of the thermoplastics exhibit a wide variation in impact strength as the temperature is varied. Most reach a brittle range if the temperature is lowered considerably. Figure 8 illustrates the variation in impact strength of cellulose acetate sheet plastic with temperature under three different conditions of notching. Ductile-to-brittle transitions similar to these are observed for metals. It is interesting to note that cutters Nos. 1 and 2 result in the same transition temperatures, although cutter No. 1 results in a lower impact strength in the ductile region. On the other hand, cutter No. 3, with a slower cutting speed, shifts the transition temperature 15 or 20 C. higher, and also produces a much lower impact strength in the ductile region. Even in the brittle region, this cutter results in a lower impact strength. Such behavior would be expected if this cutter produces a smaller radius at the bottom of the notch, or if it results in a rough or ragged notch. Actually, the latter was the case.

SUMMARY AND CONCLUSIONS

To sum up, certain well-recognized facts concerning impact strength have been reviewed. These may be listed as follows:

1. The energy to fracture depends on both the force and the deformation produced, and for brittle materials is approximately equal to $W = \frac{PS}{2}$ (Eq. 2).

2. The deformation may or may not be ductile, depending on the material, and on the conditions of temperature, speed, and the state of stress.

3. If the failure is brittle, the energy absorbed may be correlated directly with the dimensions of the specimen, the elastic modulus, and the maximum tensile stress which the material is capable of supporting.

In addition to this, experimental results involving the effects of specimen dimensions, notching, temperature, and speed are presented. Evidence is given that for many plastics the tensile strength is a linear function of the logarithm of the stressing rate over a relatively wide range of the latter.

Hazen (**24**) has pointed out some of the consequences of Eq. 2. He regards "toughness" as measured by the area under the load-deflection curve in flexure as being a more reliable indication of impact resistance than the rating as given by the standard Izod or Charpy impact test, and gives considerable experimental evidence in support of this view. Our experience has been in agreement with Hazen's. As a matter of fact, if our knowledge of the effect of speed were more complete, it might appear that there exists very little need for a conventional impact test in the field of plastics. A knowledge of the effect of speed and temperature on the tensile strength and modulus of elasticity of brittle materials should allow us to predict their toughness under a wide range of conditions.

When ductility is involved, however, there exists a need for a test or series of tests which will enable one to estimate whether or not plastic deformation will take place under a given set of conditions. One approach to this problem would be that of determining (*a*) the so-called technical cohesive strength (**26, 27, 28**), and (*b*) the yield value of the shear stress under a variety of conditions. Another approach, suggested by Seeley (**25**) and again by deForest (**9**) is that of setting up a series of standard specimens which cover a range of $\sigma_{\text{max.}}/\tau_{\text{max.}}$ values, and locating the position of the ductile-to-brittle transition under a variety of conditions with respect to this series of specimens.

The importance of the state of stress produced in the specimen during a test should be emphasized. Our experience forces us to believe that this is one of the most important factors in impact testing. Its critical nature is demonstrated clearly by the brittle-ductile transitions arising solely from changes in dimensions, a phenomenon which has been observed in the Charpy impact testing of steels.

The common belief that impact tests are physically unique may be attributed largely to a general lack of understanding among engineers as to the importance of stress states. This is no criticism, since even among experts the knowledge of this subject is at best rudimentary. Good progress is being made, however, and the time may not be far off when it will be possible to obtain an accurate picture of the engineering properties of a plastic from a relatively few laboratory determinations made at several conditions of stress state, temperature, and testing speed. When this can be done, present distinctions between static and impact tests need no longer exist.

Acknowledgments:

The authors are indebted to Mr. R. K. Swank for some of the experimental data which have been presented. Mr. M. E. Mark's permission to use the data represented in Fig. 1 is also appreciated.

REFERENCES

(**1**) D. Telfair and H. K. Nason, "Impact Testing of Plastics—I. Energy Considerations," *Proceedings*, Am. Soc. Testing Mats., Vol. 43, p. 1211 (1943).

(**2**) George Lubin, "Preliminary Studies on a Drop Ball Impact Machine," ASTM BULLETIN, No. 128, May, 1944, p. 13.

(**3**) R. Burns, Single-blow impact, and impact fatigue as measured by a ball-bearing drop-weight method. (Private Communication, 1942.)

(**4**) C. R. Stock, "A Ball Impact Tester for Plastics," ASTM BULLETIN, No. 130, October, 1944, p. 21.

(**5**) L. H. Callendar, "New Methods for Mechanical Testing of Plastics," *British Plastics*, Part I, Vol. 13, p. 445 (1942); *British Plastics*, Part II, Vol. 13, p. 506 (1942).

(**6**) H. F. Church, H. A. Daynes, "The Falling Weight Impact Test for Ebonite," *Transactions*, Inst. of Rubber Ind., Vol. 13, p. 96 (1937).

(7) D. J. McAdam and R. W. Clyne, "The Theory of Impact Testing: Influence of Temperature, Velocity of Deformation, and Form and Size of Specimen on Work of Deformation." Symposium on Impact Testing, *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part II, p. 112 (1938).

(8) S. L. Hoyt, "Notched-bar Testing and Impact Testing," *Proceedings*, Am. Soc. Testing Mats., Vol. 38, Part II, p. 141 (1938).

(9) A. V. deForest, "Some Complexities of Impact Strength," Henry Howe Memorial Lecture presented at February, 1941 meeting of the Am. Inst. Mining and Met. Engrs., New York, N. Y. *Metals Technology*, Am. Inst. Mining and Met. Engrs., Vol. 8, No. 5 (Aug., 1941).

(10) K. G. Olsson, "The Impact-Tension Test and Its Application Possibilities," Reports of Iron and Steel Institute (Jernkontor) Annual Series 125, Vol. 6, 1941 (translated from Swedish, by Ann DiIulio).

(11) C. W. MacGregor and J. C. Fisher, "Relations Between the Notched Beam Impact Test and the Static Tension Test," *Journal Applied Mechanics*, Am. Soc. Mech. Engrs., Vol. II, p. A-28 (March, 1944).

(12) Maxwell Gensamer, "The Strength of Metals Under Combined Stresses," A.S.M. Lecture, October, 1940. Issued as separate publication by Am. Soc. Metals.

(13) O. R. J. Lee "The Notched Bar Test," *Journal*, Inst. Mech. Eng. Vol. 143, 114–121 (June, 1940).

(14) D. Telfair, T. S. Carswell, and H. K. Nason, "Creep Properties of Molded Phenolic Plastics," *Modern Plastics*, Vol. 21, No. 6, February, 1944, p. 137.

(15) B. J. Lazan, "Some Mechanical Properties of Plastics and Metals under Sustained Vibrations," *Transactions*, Am. Soc. Mechanical Engrs., Vol. 65, No. 2, p. 87 (1943).

(16) H. Leadermann, "Creep, Elastic Hysteresis and Damping in Bakelite Under Torsion," *Transactions*, Am. Soc. Mechanical Engrs., p. 61, A-79 (1939).

(17) E. Salewski and R. Nitsche, "Impact-bending Strength at High and Low Temperatures," *Kunstotoffe*, Vol. 31, p. 381 (1941).

(18) T. S. Carswell, R. E. Hayes, and H. K. Nason, "Physical Properties of Polystyrene as Influenced by Temperature," *Ind. and Eng. Chem.* (Ind. Ed.) Vol. 34, p. 354 (1942).

(19) T. S. Carswell, D. Telfair, and R. U. Haslanger, "The Influence of Temperature on the Mechanical Properties of Molded Phenolic Materials," *Proceedings*, Am. Soc. Testing Mats., Vol. 42, p. 944 (1942).

(20) Rohm and Haas Co., "Strength Properties of Plexiglas, Part I," *Aviation*, Vol. 42, No. 1, January, 1943, p. 128.

(21) F. B. Fuller, "Engineering Properties of Plastics," *Modern Plastics*, Vol. 20, No. 10, June, 1943, p. 95.

(22) Philip M. Field, "Basic Physical Properties of Laminates," *Modern Plastics*, Vol. 20, No. 12, August, 1943, p. 91.

(23) T. S. Carswell, D. Telfair, R. U. Haslanger, "Effect of Continuous Heat on Phenolics," *Modern Plastics*, Vol. 20, No. 6, February, 1943, p. 79.

(24) T. Hazen, "Toughness of Molding Materials," *Modern Plastics*, Vol. 21, No. 2, October, 1943, pp. 103–6, 144.

(25) F. B. Seely, "The Strength Features of the Tension Test," *Proceedings*, Am. Soc. Testing Mats., Vol. 40, p. 535 (1940).

(26) W. Kuntze, "Kohasonsfestigkeit," *Mitteilungen*, der deutschen Material—prufungsanstaltin, Sanderheft XX, Julius Springer, Berlin (1932).

(27) D. T. McAdam, Jr., "The Technical Cohesive Strength of Metals," *Transactions*, Am. Soc. Mechanical Engrs., Vol. 63, *Journal Applied Mechanics*, Vol. 8, p. A155 (1941).

(28) D. T. McAdam and R. W. Mebs, "The Technical Cohesive Strength and Other Mechanical Properties of Metals at Low Temperatures," *Proceedings*, Am. Soc. Testing Mats., Vol. 43, p. 661 (1943).

(29) T. S. Carswell and H. K. Nason, "Effect of Environmental Conditions on Mechanical Properties of Organic Plastics," Part I, *Modern Plastics*, Vol. 21, No. 10, June, 1944, p. 121; Part II, *Modern Plastics*, Vol. 21, No. 11, July, 1944, p. 125.

DISCUSSION

MR. W. N. FINDLEY.[1]—The authors have added considerably to our knowledge of impact testing technique and it is to be hoped that they will continue this valuable series of articles.

Referring to the relation between Izod impact strength and striking velocity, Fig. 8, the authors state "Intuitively, one would expect the slopes of these curves to 'level off,' or approach zero both for extremely low and extremely high speeds. . . . . Further experimental work along this line will be very interesting."

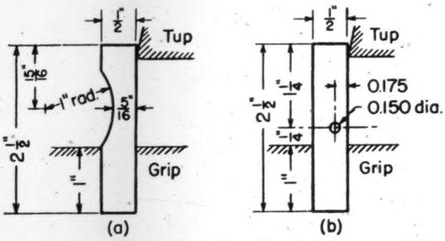


FIG. 1.—Impact Specimens.

I believe one might find that the same data when plotted on double logarithmic paper, instead of semi-logarithmic, as used by the authors, would still fit straight lines rather well and would correspond to an equation entirely different from that which the authors have used to represent those data and yet would yield a more rational physical interpretation at the two extremes. The equation would then be a power function instead of a logarithmic function.

With regard to methods of impact testing, there are two types of impact specimens which, so far as I know, have not been tried with plastics which might eliminate some of the difficulties mentioned by the authors.

One of these specimens, shown in the accompanying Fig. 1(*a*), has been used in a slightly different form by the writer for repeated impact tests.[2] Instead of a sharp notch, this specimen has a "notch" with a large radius which can be cut to accurate dimensions more easily than the standard notch. Also the sharpness of the cutter can be controlled more easily for the large radius (using a fly-cutter) than the form cutter used for the sharp notch.

The other specimen, Fig. 1(*b*), was investigated in Sweden.[3] This investigator found his test bar when used as a Charpy specimen gave better differentiation between different metals than the regular notched Charpy bar. There was also less scatter than with the Charpy bar.

Another advantage of the hole-specimen, Fig. 1(*b*), is that a molded surface can be used at the critical section without the difficulty of molding an accurate notch.

A possible source of error in the notched Izod bar lies in the fact that the specimen is gripped at the notch so that unknown stresses may be set up in the notch due to the clamping pressure.

---

[1] Assistant Professor of Theoretical and Applied Mechanics, College of Engineering, University of Illinois, Urbana, Ill.

[2] W. N. Findley and O. E. Hintz, Jr., "The Relation Between Results of Repeated Blow Impact Tests and of Fatigue Tests," *Proceedings*, Am. Soc. Testing Mats., Vol. 43, p. 1226 (1943).

[3] Axel Wahlsteen, "Investigations of a New Test Bar Form for Impact Tests," Report of the Steel and Iron Institute (Jernkontor) on Technical Research Work.

This source of error could be eliminated by clamping the specimen lower down—say $\frac{1}{4}$ in. below the notch.

MR. C. R. STOCK.[4]—I should like to point out, for the benefit of those who are not as well acquainted with the situation as are those who are on Subcommittee VIII of Committee D-20 on Plastics that there are two distinct phases to the problem of impact testing and these phases have been the main topics of discussion of the subcommittee until recently.

The problem of the interior stresses in the specimen is certainly one that has been covered at present extremely well and is one that is very necessary for an analysis of the impact strength of plastics as well as of other materials.

However, another problem which comes up in this work is that of the mechanism for producing impact. This has been gone over very thoroughly in the past several years, both here and in England, but the fact still remains that most of the impact testing is done by a method of difference; that is, the impact strength of a material, by one means or another, is estimated as the difference in energy in a machine before and after the impact takes place.

This is a perfectly feasible method of evaluating impact strength, but it leads one into difficulties that are rather hard to surmount. I am acquainted with these factors personally as a result of committee association with the work of Messrs. Nason and Telfair.

All of the methods for testing plastics that are encountered now, whether they are known outside this committee or within it, make use of the method of testing by difference. It seems to me that it would be a good direction for the committee to take to look into the possibility of direct measurement, making use of the relationship brought out by the authors—the relationship of the area under the stress-strain curve to the energy absorbed in breaking the specimen.

It seems plausible that the mechanism for making the break could be so arranged that a direct measurement of the energy expended in the specimen could be made, rather than estimating the energy lost in the specimen not only to initiate the fracture but also to propagate it, to take care of shear and also the kinetic errors that can be partially and sometimes entirely removed by measurement of the velocity of the broken end of the specimen after it is broken off.

I should like to bring this possibility to the attention of this group because some constructive ideas may be obtained. I have a few but I would rather work them out privately, to eliminate the stupid ones where only I will be embarrassed.

MR. E. L. HETTINGER.[5]—I wonder whether any thought has been given to the application of these fracturing tests to plastics used in head and eye protective devices. Tests for plastics used for this purpose should be given serious consideration.

MESSRS. DAVID TELFAIR[6] AND HOWARD K. NASON[6] (*authors' closure, by letter*).—Mr. Findley's discussion of some of the alternatives to the present standard notch is very much to the point. A larger radius at the base of the notch would undoubtedly be an improvement, but the hole-specimen, Fig. 1(*b*), would appear to be the most promising.

As Mr. Stock has pointed out, an ideal impact test would be one which measured directly the energy absorbed by the specimen while it is under load. We know of no method of accomplishing this which would lend itself to routine control testing by an unskilled operator. On a research basis, however, such energy measurements could be made in the form of high speed load-deflection, or load-extension curves, and would undoubtedly yield valuable information.

---

[4] Physicist, Physics Div., Stamford Laboratories, American Cyanamid Co., Stamford, Conn.

[5] Optical Research Dept., Willson Products, Inc., Reading, Pa.

[6] In Charge of Physical Testing and Assistant Director of Research, respectively, Plastics Division, Monsanto Chemical Co., Springfield, Mass.

FLOW OF THERMOSETTING PLASTICS AT ELEVATED TEMPERATURES

By J. Delmonte[1] and E. Watkins[1]

The forming and drawing of fully cured, thermosetting laminated phenolic sheets has attained considerable importance in recent months (**1, 2**).[2] In this process, commercial sheets of grade C laminated phenolic plastic are subjected to high temperatures for a few minutes, and are then placed in forming jigs and shaped much like thermoplastic sheet stock. Numerous aircraft parts and equipment are now being fabricated from the formed material, and the technique gives every promise of extending widely the field of laminated phenolics. Because fully cured stocks have been formed, the question has arisen as to the exact definition of a thermosetting material, which presumably is infusible and insoluble. Apparently it possesses some thermoplastic qualities at elevated temperatures.

In the current investigation, a method was sought for evaluating the thermoplastic properties of fully cured thermosetting laminates at elevated temperatures (above 300 F.), inasmuch as no data of this nature have been reported in the literature. By this technique it is hoped that means will be made available for evaluating various grades of thermosetting laminates with respect to their formability at high temperatures. Canvas-base laminated phenolics have been chosen both because they have higher impact strength than the paper grades and because they blister less at elevated temperatures and atmospheric pressure.

The fact that properties such as creep rates may increase tenfold in going from 75 to 200 F. (**3**) and that flexural strength, tensile strength, compressive strength, etc., decrease at elevated temperatures (**4**) is indicative of the "softening" of thermosetting materials. In fact, a loss of approximately 30 per cent flexural strength in going from room temperature to 300 F. has been reported (**4**). However, as a group, thermosetting materials are less sensitive to temperature changes than are thermoplastics.

Test Method:

The test method employed in this examination was a modified form of the A.S.T.M. Tentative Method of Test for Distortion Under Heat of Molded Electrical Insulating Materials (D 648-41T).[3] The recorder and follower rod which records the deflection at the center of the test specimen can be seen in the apparatus shown in Fig. 1. Instead of heating the plastic material at a slow controlled rate as required for the A.S.T.M. heat distortion point determination, an oil bath already heated to a predetermined temperature was employed. Several variables of applying load and temperatures were explored, including the times of immersion in the hot oil before applying load. However, in the method finally adopted, the test specimen was loaded for about 10 sec. in the open and then covered with hot oil. The calculated load was applied for

---

[1] Plastics Industries Technical Institute, Los Angeles, Calif.

[2] The boldface numbers in parentheses refer to the reports and papers appearing in the list of references appended to this paper, see p. 1015

[3] 1942 Book of A.S.T.M. Standards, Part III, p. 1066.

10 sec. after introducing the oil. The deformation at the center of the specimen was recorded automatically as a function of time. This exact procedure was followed throughout all tests, since preliminary tests showed that accuracy would be affected if these precautions were not taken. For example, if the test specimen is immersed in the hot oil too long before the load is applied, further cure of the material may interfere with its high-temperature flow properties. It was realized of course, that the high temperature would bring about further polymerization, though the test was designed to demonstrate the immediate softening or plasticizing effect of high temperatures on thermosetting compounds.

The tests were conducted upon specimens measuring approximately 5 in. long by $\frac{1}{2}$ in. wide, $\frac{1}{8}$ and $\frac{1}{4}$ in. thick. They were mounted upon the standard 4-in. span for flexural and heat distortion tests. Constant loads were applied by means of a rod and member with $\frac{1}{4}$ in. diameter at the end. This load was maintained in position throughout the entire test. The rod and chain recording system employed in A.S.T.M. Method of Test for Measuring Flow Temperatures of thermoplastic Molding Materials (D 569 - 43)[4] were adapted to the requirements of this test. In calculating weights to be added to the center of the span, the weight of the follower rod was taken into consideration. The maximum deformation capable of being measured by this test arrangement was $1\frac{1}{2}$ in. Tem-

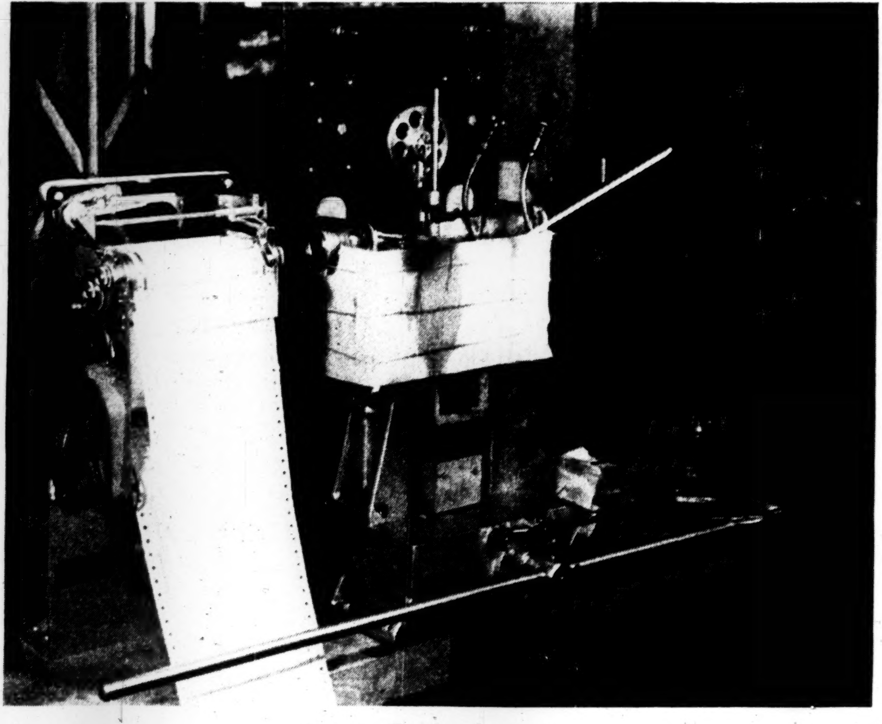


FIG. 1.—Testing Apparatus.

---

[4] 1943 Supplement to Book of A.S.T.M. Standards, Part III, p. 104.

peratures were held within ± 5 F. and recorded on individual curves showing deformation *versus* time under stress. An electrical immersion heater placed in the container (see Fig. 1) maintained the oil at a constant temperature during test. While temperatures in excess of 400 F. are commonly employed in forming and drawing thermosetting laminates, the maximum temperature investigated was 400 F., because above this range blisters may form and interfere with accuracy of the deflection readings.

In effect, this test method is a measure of flexural deformation of thermosetting materials at temperatures of 300 to 400 F. at maximum fiber stresses of 500 to 1000 psi. The radical change in deformation rates was quite noticable for some of the materials tested when making comparisons between data for 300 and 400 F. In general, it may be considered that a fast deformation rate under constant stress is indicative of good formability. Tests were conducted to determine the instantaneous elastic deformation of thoroughly heated thermosetting laminates. At 375 F., this deformation proved to be approximately 40 per cent of total deformation after 2 min.

Materials Tested:

Inasmuch as this particular test method was designed for the evaluation of formability of thermosetting laminates at elevated temperature, the tests were confined to thermosetting laminates. Dry and 50 per cent relative humidity preconditioning was applied to a selected group of laminates with no observable effect on the results. Various variables within the laminates themselves were explored including: (1) effect of curing time, (2) effect of specimen size, and (3) influence of cloth reinforcement. In addition, several commercial grades of heat-forming, thermosetting laminates were selected and compared under standard test conditions established by this paper. Samples included "Micarta" grade 444, and "Formica" CN-11 laminated phenolic. In addition, the formability of cured molded phenolics was demonstrated by testing a wood-flour filled molded phenolic.

Stress Calculations:

When the load is applied at the center of a beam, the maximum fiber stress is calculated from the well-known formula for rectangular beams:

$$\text{Stress} = \frac{3 \times P \times l}{2bd^2}$$

where:

P = load in lb.
l = span length in in.
b = width in inches
d = thickness in inches.

Loads were calculated to develop fiber stresses up to 1000 psi. for the various beams tested. For effective, comparative results, stresses at 500 psi. and 1000 psi. proved adequate for the $\frac{1}{4}$ in. thick beam. These stress values are appreciably greater than the 266 psi. upon $\frac{1}{2}$ in. by $\frac{1}{2}$ in. by 5 in. beams recommended in Method D 648 for the heat distortion test. Lower stress values of 100 and 200 psi. were examined in plotting the deformation of some $\frac{1}{4}$-in. thick beams, within the temperature range employed. These lower stress values did not cause large enough deformations to afford ready comparison of results. Rather than resort to higher temperatures for comparison, higher stress values were employed because they provided smooth comparative curves.

Interpretation of Charts:

Figures 2 to 6, inclusive, show typical results obtained in recording the deformation at the center of a 4-in. span for laminated phenolics loaded under maximum fiber stresses of 500 and 1000 psi. Each curve is the average of two or three runs. The grade C laminate shown in Fig. 3 was fully cured in the press prior to test. Its deformation rate increased almost seven-fold between 300 and 400 F.

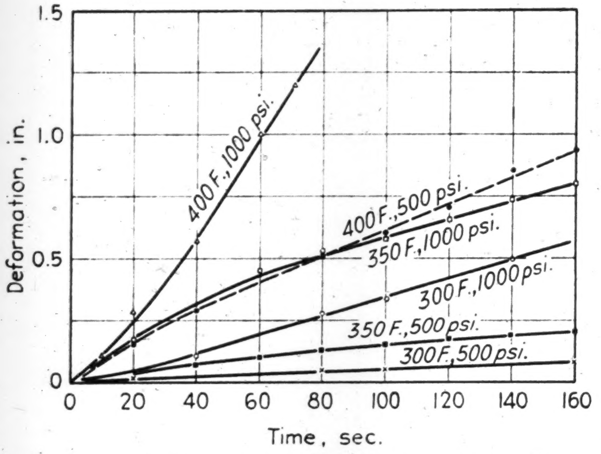


FIG. 2.—Standard ⅛-in. Grade C Laminated Phenolic.

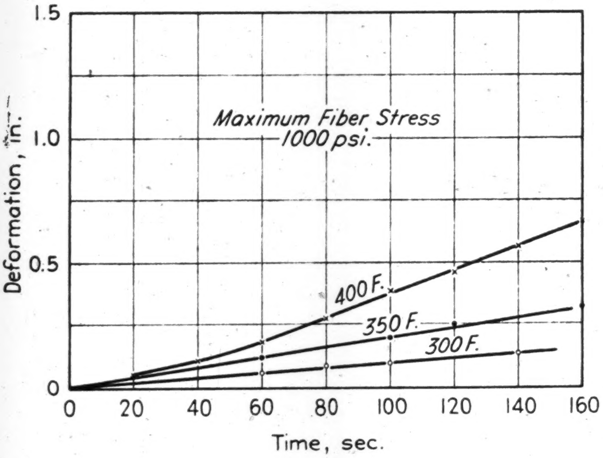


Fig. 3.—Standard ¼-in. Grade C Laminated Phenolic.

The influence of curing time of laminated phenolics upon the high-temperature flow is quite marked, as shown in Fig. 4. Apparently slight undercure in the laminate will facilitate forming. This practice has, in fact, been put into effect in commercial forming grade laminates. Also noteworthy is the similar behavior of a 30 min. and 120 min. cured specimen, indicating that even excessive overcure will not effect the hot formability of the materials.

Beach (2) has already pointed out that good formability of thermosetting laminates is secured when the cloth is cut on the bias, and this is verified in Fig. 5 where a large difference exists between the bias cut and the straight weave samples. The good flow characteristics of molded phenolic plastics demonstrated in Fig. 6 indicate a performance comparable with the phenolic resins in the laminated pieces.

Figure 7 illustrates some completed formed thermosetting laminates.

Summary:

It is hoped that the methods discussed in this paper will be found useful for evaluating the high temperature flow properties of thermosetting laminates. The most favorable conditions for affording comparisons between thermosetting laminates appear to be an oil bath tem-

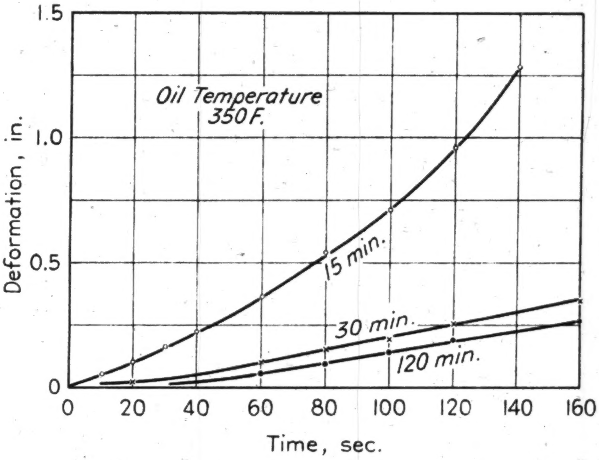


FIG. 4.—Influence of Curing Time of Laminated Phenolics Upon the High-Temperature Flow Characteristics.

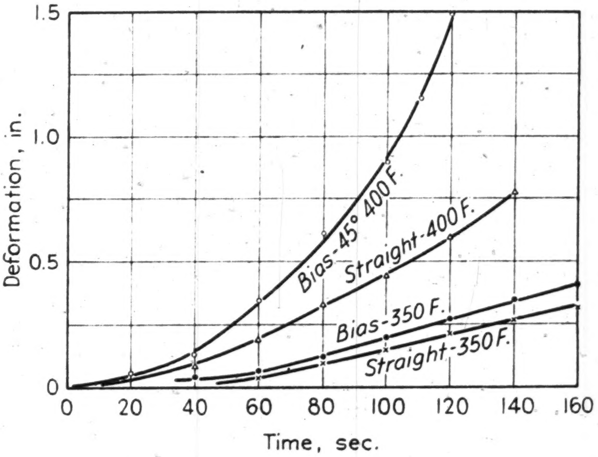


FIG. 5.—Influence of Cloth Weave.

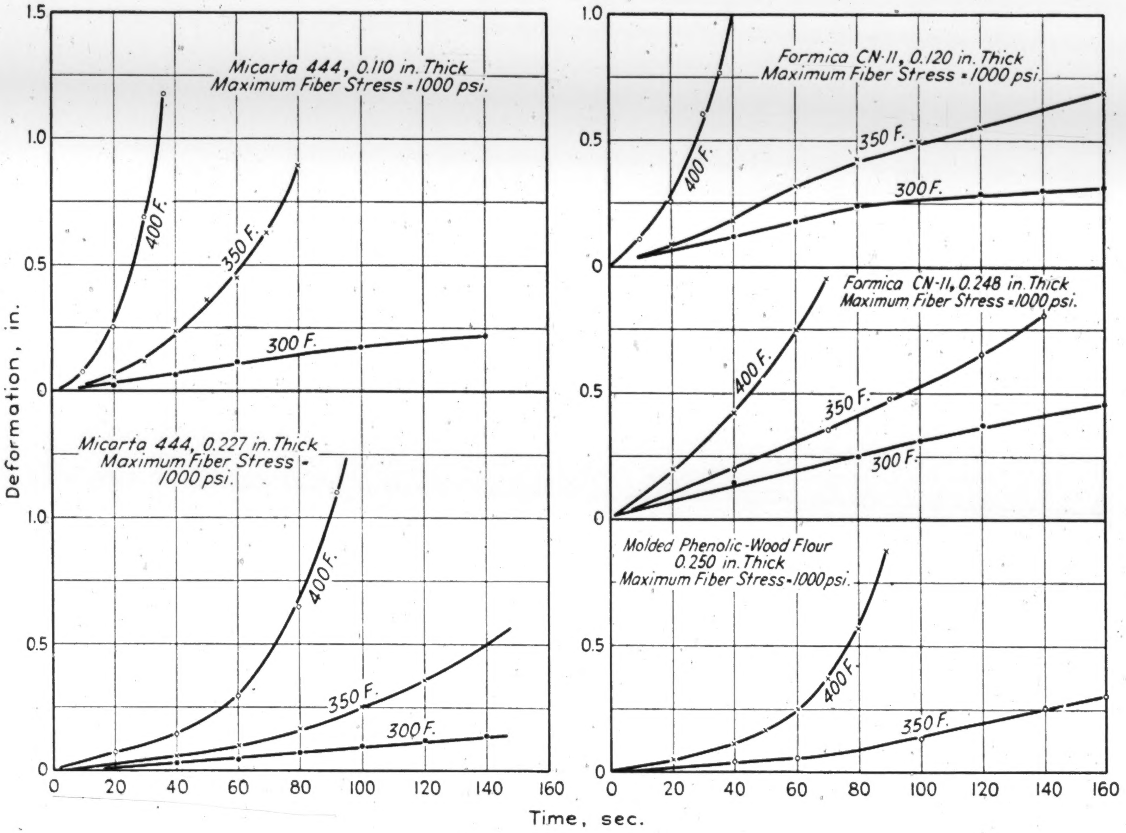


FIG. 6.—Characteristic Deformation Curves.

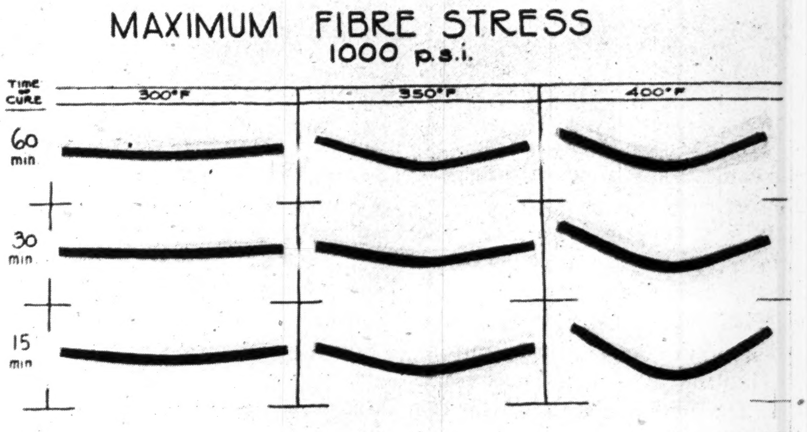


FIG. 7.—Some Completed Formed Thermosetting Laminates.

perature of 400 F., a stress of 1000 psi., and a material thickness of $\frac{1}{4}$ in. Time to reach $\frac{1}{2}$-in. deformation is reported in Table I.

The fast sweep upwards of the deformation curve appears to be a criterion of good formability or fast rate of creep. Of course, the materials hold their shape after being cooled down to room temperature, though they are subjected to reforming on reheating to an elevated temperature. The test data conclusively demonstrate the thermoplastic properties of phenolic plastics at high temperatures.

TABLE I

Material Tested	Thickness, in.	Time to Reach ½ in. Deformation at 400 F. and 1000 psi., sec.
Grade C—Laminated Phenolic	0.250	125
Formica CN-11	0.248	46
Micarta 444	0.227	72

REFERENCES

(1) Lougee, "Thermoelastic C-Stage Laminates," *Modern Plastics*, Vol. 20, June, 1943, p. 69.

(2) Beach, "Effects of Thermo-elastic Forming on Properties of Thermosetting Laminates," *Modern Plastics*, Vol. 21, January, 1944, p. 127.

(3) J. Delmonte and W. Dewar, "Factors Influencing Creep and Cold Flow of Plastics," ASTM BULLETIN, No. 112, October, 1941, p. 35.

(4) T. S. Carswell, D. Telfair, and R. U. Haslanger, "Influence of Temperature on Mechanical Properties of Molded Phenolic Materials," *Proceedings*, Am. Soc. Testing Mats., Vol. 42, p. 944 (1942).

DISCUSSION

MR. HENRY GRINSFELDER.[1]—Two questions came to my mind with respect to this paper.

First, it is always disturbing, as the representative of a resin manufacturer, to hear the term "fully cured" used quite generally without a good definition of it, and I should like to ask the author for his definition of a fully-cured resin.

Second, I should like to ask if in the second heating process there is not some weakening of the material due to the extra heat, either in tensile strength or some other strength property.

MR. JOHN DELMONTE[2] (*author's closure, by letter*).—In reply to Mr. Grinsfelder's questions, I am happy to note that he too, questions the interpretation of a "fully-cured" laminate. Before the thermoplastic properties of phenolic laminates at high temperatures were manifested in such techniques as "post-forming," it was the practice to recognize a "fully-cured" phenolic laminate by the attainment of a peak in physical properties after a suitable cure period. This recognition is justified when such measurements are performed at room temperatures, and when the materials are to operate in proximity to such temperatures. High-temperature forming invites new definitions of thermosetting materials and the methods in this paper suggest a basis for evaluating thermosetting materials at high temperature. Inasmuch as we have not encountered a thermosetting material which will not exhibit deformation under sustained stress at high temperatures, we may find it expedient to classify thermosetting materials according to the degree with which they respond to loads at high temperatures.

Prolonged heating above 300 F. is well known to be detrimental to phenolic resins. However, in the 1 or 2 min. exposure to the high temperatures required for "post-forming" there is also a beneficial action on forming and stretching the cloth laminate, due to better orientation of textile fibers. Within this short time interval, the over-all effect noted has been an improvement in physical properties.

---

[1] Senior Engineer, The Resinous Products & Chemical Co., Philadelphia, Pa.

[2] Technical Director, Plastics Industries Technical Institute, Los Angeles, Calif.

CHARACTERISTICS OF THE TUCKERMAN STRAIN GAGE

By Bruce L. Wilson[1]

Synopsis

By means of an interferometric calibration device used at the National Bureau of Standards for calibrating gages and autocollimators, experimental results are secured which indicate the variations of the calibration factor with different conditions of use. The results indicate that (1) the change in autocollimator reading is accurately proportional to the change in length of the gage length of the strain gage, (2) the calibration factor is not greatly influenced by the material of the specimen provided the gage is properly attached, (3) the calibration factor is practically independent of the position of the gage in space, and (4) the calibration factor is almost independent of the temperature within the range 70 to 100 F. Provided the gage is properly attached, the change in calibration factor due to position of the gage and variations in material of the specimen does not exceed 0.1 per cent. Variations in mounting force from 1 oz. to 20 lb. reduced the calibration factor by as much as 0.9 per cent for celluloid and by less than 0.3 per cent for duralumin. By standardizing the mounting force during calibration and use, errors due to variations in mounting force can be eliminated. Results indicate that for nonvibrating specimens it is desirable to attach the gages by means of low spring-constant springs deflected to push the lozenge against the specimen with a force not exceeding 1 lb.

Because of the sensitivity, the small size, and the light weight of the Tuckerman strain gage, it is well adapted to measuring deformations of specimens and structures over short gage lengths. It is now being applied in the laboratories of the National Bureau of Standards and elsewhere to a large variety of problems, many of which involve the testing of specimens or structures made of thin sheet materials. It is customary to calibrate the gages with their lozenge axes and gage axes horizontal and with the gages held in place during calibration with a force of a few ounces in addition to the weights of the gages. They are actually used in many different positions, with different mounting forces and on materials of widely varying mechanical properties. Since it has been shown by Vose[2] that the conditions of use may alter the calibration factors of Huggenberger tensometers by as much as 5 per cent, the question naturally arises as to the magnitude of the variation of the calibration factor of a Tuckerman strain gage under various conditions of use.

To determine the variation of the calibration factors of a typical gage of current design when subjected to widely different conditions of use, the gage was calibrated by means of an interferometric calibration device for five different positions, at two different temperatures, for mounting forces varying from the weight of the gage (about 1 oz.) to 20 lb., and on a variety of materials having Vickers numbers from about 10 to 800.

---

[1] Associate Physicist, National Bureau of Standards, Washington, D. C.

[2] R. W. Vose, "Characteristics of the Huggenberger Tensometer," *Proceedings*, Am. Soc. Testing Mats., Vol. 34, Part II, p. 862 (1934).

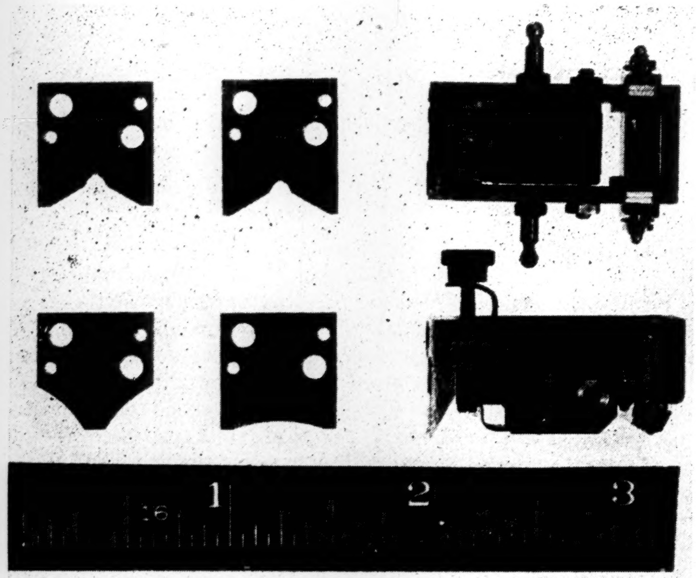


FIG. 1.—Tuckerman Strain Gages, Gage Length 1 in., Lozenge Diagonal 0.2 in., with Knife-edges for Use on All Shapes of Specimens.

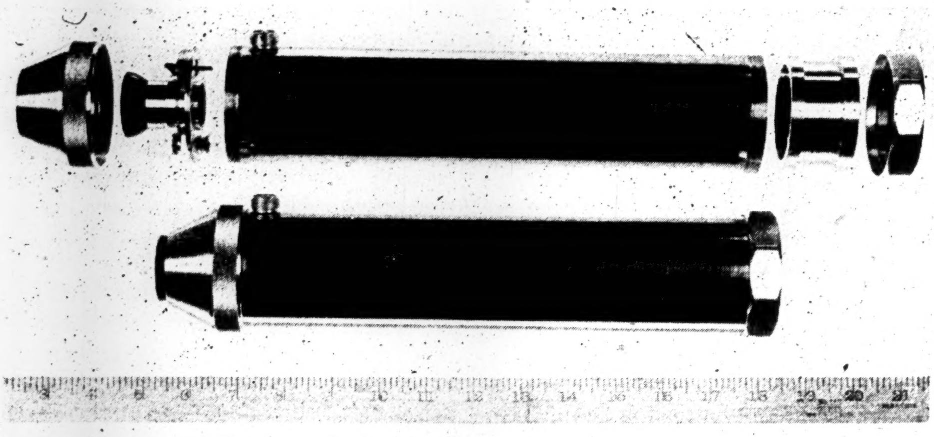


FIG. 2.—Tuckerman Autocollimator for Use with Optical Strain Gages.

DESCRIPTION OF AUTOCOLLIMATOR AND STRAIN GAGE

Two 1-in. gage length Tuckerman strain gages having 0.2-in. lozenges, and the four different types of knife-edges required to adapt the gage to various-shaped specimens, are shown in Fig. 1. Two autocollimators, one disassembled to show the Ramsden eyepiece and lamp assembly and the objective lens cell, are shown in Fig. 2.

When the device is in use, the gage is attached to the specimen or structure, and the autocollimator is separately supported or held in the hand. A 1-in. gage weighs about 1 oz., the autocollimator weighs about 2 lb. The gages are about $1\frac{1}{4}$ in. wide, project about 1 in. above the surfaces to which they are attached, and are only slightly longer than their gage lengths.

A complete description of the Tuckerman autocollimator and the combination double and triple mirror system used in the strain gage has been given by Tuckerman.[3] Many improvements in the details of the design of the autocollimator and gages have been made since 1923, but the basic principles of the design have not been altered. For this reason only a brief description of the instruments is given here.

A diagrammatic sketch of the autocollimator and gage is shown in Fig. 3. The autocollimator consists of a highly corrected two-component objective lens having a focal length of about 250 mm., a reticule having a uniformly graduated scale, a fiduciary line and vernier accurately positioned to lie in the focal plane of the objective lens, a lamp for illuminating the fiduciary line and vernier, and a Ramsden type eyepiece. Reticules, which are produced photographically on glass, are mounted in cells which bear against definitely positioned stops in the autocollimator tube so that they can be removed and replaced without changing the calibration of the instrument. Likewise the objective lens is mounted in a cell which bears against a stop in the tube and it may be removed for cleaning and replaced without changing the calibration of the instrument.

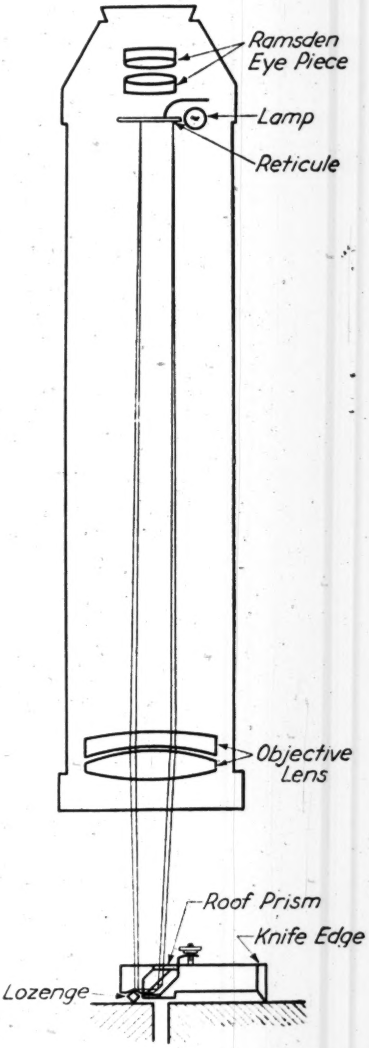


FIG. 3.—Diagrammatic Sketch of the Tuckerman Autocollimator and Strain Gage.

The gage consists of a steel or aluminum body to which is attached a knife-edge and the parts of the mirror system, which consists of the lozenge and the roof prism. The movable mirror is one surface of the lozenge, which rests in seats formed by hardened steel plates attached to the gage body, and rotates about an axis perpendicular to the axis of the gage. The two fixed, mutually perpendicular mirrors of the three-mirror system are the roofs of a prism mounted in a housing which can be rotated by means of a knurled nut to reset the gage. The prism rotates about an axis perpendicular to the plane which bisects the dihedral angle formed by the roof surfaces. As the specimen deforms, the lozenge rotates about an axis perpendicular to this plane.

---

[3] L. B. Tuckerman, "Optical Strain Gages and Extensometers," *Proceedings*, Am. Soc. Testing Mats., Vol. 23, Part II, p. 602 (1923).

The roof prism contains a third reflecting surface, known as the flash surface, which, together with the lozenge, forms the two-mirror system. This surface is parallel to the line of intersection of the two roof surfaces and perpendicular to the plane which bisects the dihedral angle formed by the roof surfaces. When the instrument is read, it is necessary to have the image reflected from the flash surface in the field of view, to avoid the introduction of a cosine error.

Light from the fiduciary line and vernier scale is rendered parallel in passing through the objective lens of the autocollimator and falls upon both the lozenge and the roof prism. Only the light which falls upon the roof prism is shown in Fig. 3. This light is reflected by the two roof surfaces of the prism and by the surface of the lozenge, back into the objective lens to form an image on the scale of the reticule. Deformation of the surface upon which the gage rests will result in a rotation of the lozenge and will move the image along the scale.

The image shown in Fig. 3 is called the compression image. A tension image, not shown in Fig. 3, is formed by the light which falls first upon the lozenge. This image would not be visible through the eyepiece because it would lie as far to the right of the fiduciary line as the compression image shown lies to the left.

As the lozenge is rotated to move the compression image toward the fiduciary line (toward 0 on the visible scale) both the visible compression image and the invisible tension image will approach the fiduciary line. If the rotation is continued, the compression image will disappear from view after passing the 0 scale line and the tension image will appear and move up the scale. Since the distance from the fiduciary line to the 0 scale line is equivalent to 5 numbered divisions, neither image is visible for a rotation of the lozenge corresponding to 10 numbered divisions. If the incident and reflected light from the gage are parallel, the image of the fiduciary line lies on the line itself and is, therefore, masked from the field of view.

The scale of the reticule, which is about $\frac{1}{2}$ in. in length, is graduated into 25 numbered divisions, each of which is subdivided into 5 divisions, making a total of 125 divisions. Tenths of a division may be read from the vernier. By "splitting" a vernier division twentieths of a division may be estimated. Each numbered division corresponds to 0.001 radians rotation of the lozenge. An image is obtainable from a gage provided the angle between the incident and reflected light lies within the range 0.005 to 0.030 radians.

For the gages shown in Fig. 1, having 0.2-in. lozenges, one numbered division corresponds to a deformation of 2×10^{-4} in., and one vernier division corresponds to a deformation of 4×10^{-6} in. During calibration the autocollimator is read to one-half vernier division, which corresponds to a deformation of 2×10^{-6} in.

THE CALIBRATION DEVICE

The device used to calibrate Tuckerman strain gages at the National Bureau of Standards is shown in Fig. 4. It consists of a rigid frame to which one fixture for supporting the strain gage is attached, and a movable piece, supported by two flexure plates, to which the other fixture for supporting the gage is attached. The movable fixture is moved relative to the frame by means of a screw actuated by a worm gear. Provision is made for attaching plates of different materials to the fixed and movable fixtures to permit the calibration of gages on different materials. The pitch of the screw and the reduction of the worm gear are such that no difficulty is experienced in making adjustments to less than one-millionth of an inch.

The change in length of the gage length of the instrument being calibrated is measured by means of an interference method originated by Fizeau[4] and described by Tuckerman.[3] Light from a helium lamp is reflected from two interferometer plates attached to the frame and the movable piece of the cali-

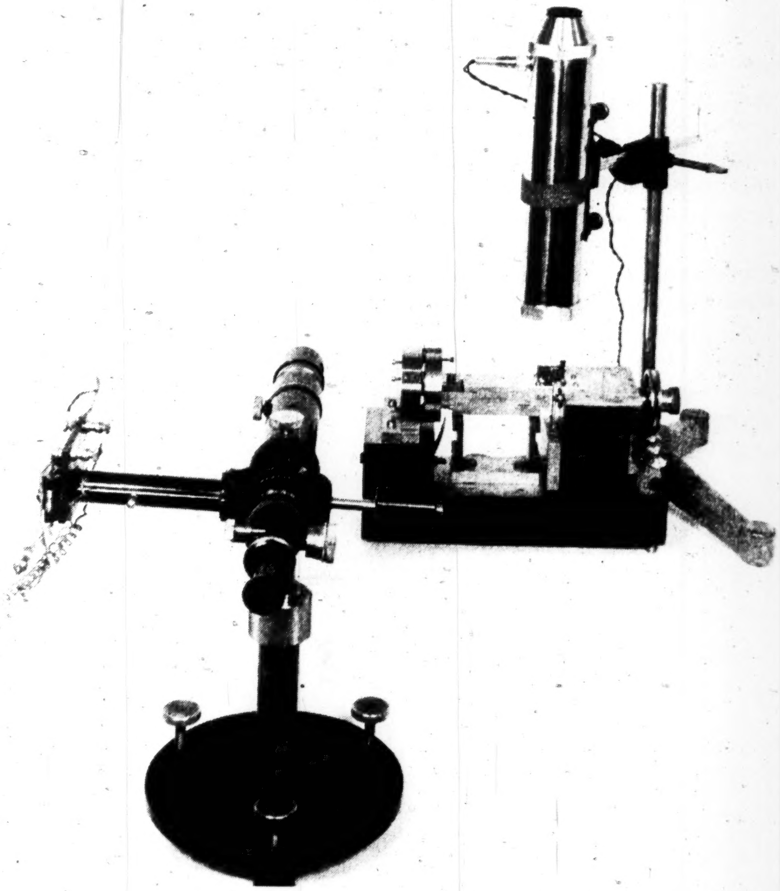


FIG. 4.—Interferometric Calibration Device for Calibrating Tuckerman Strain Gages.

---

[4] L. Fizeau, *Ann. Physik*, Vol. 128, p. 564 (1866).

bration device, respectively. The interference bands are viewed through a Pulfrich spectral system and the reading consists of counting the bands which pass the fiduciary mark (double cross hairs). One band corresponds to a displacement of the movable piece relative to the frame of one-half wave length of the line used, 0.00001156615 in.

Over the usable range of the calibration device, the distance between bands remains relatively constant and rotation of the bands with respect to the fiduciary mark is negligible. These are positive indications that the motion of the movable piece is practically a pure translation.

The calibration device is usually used in the position shown, with the surfaces to which the gages are attached horizontal. It may, however, be used satisfactorily in other positions to determine the calibration factors of gages in different positions.

The gage shown on the calibration device is held in place by a weight of 1 lb. supported equally by the two side bars which project from the gage body. This method is used for the routine calibration of gages. The calibration device functions satisfactorily with as much as 20 lb. applied to the gage. Forces greater than 1 lb. are applied by means of a lever and weights.

BEHAVIOR OF THE GAGE

Linear Relationship:

The calibration results for one complete run on a typical gage are given in Table I. The gage length of the gage was being shortened during the run. During the first five readings the tension image was in view, between the fifth and sixth readings the tension image disappeared from view and the compression image appeared. During the last five readings the compression image was in view. In calculating the change in observed autocollimator reading, the 10.00 divisions corresponding to a change in reading from 0.00 with the tension image to 0.00 with the compression image (twice the distance from the fiduciary line to the 0 scale line) were added to the results calculated from the readings of the compression image. The equation of the least squares line calculated from the results given in columns 1 and 3, assuming that only the autocollimator readings were subject to error, is given in footnote *c* and the values calculated from this equation are given in column 4. The differences between the observed and calculated autocollimator readings, given in column 5, represent the departure of the readings from a truly linear relationship, The maximum difference is 0.017 divisions, which is less than one vernier division (0.02 division).

TABLE I.—CALIBRATION DATA FOR A TYPICAL TUCKERMAN STRAIN GAGE.

Gage length 1 in., lozenge diagonal 0.2 in.

Number of Bands[a]	Autocollimator Reading, divisions[b]	Change In Autocollimator Reading, divisions		Difference Between Observed and Calculated Changes in Autocollimator Readings, divisions
		Observed	Calculated[c]	
0	21.48	0	−0.011	0.011
50	18.58	2.90	2.897	0.003
150	12.78	8.70	8.712	−0.012
250	6.96	14.52	14.528	−0.008
350	1.12	20.36	20.343	0.017
550	0.48	31.96	31.973	−0.013
650	6.30	37.78	37.788	−0.008
750	12.12	43.60	43.604	−0.004
850	17.94	49.42	49.419	0.001
900	20.86	52.34	52.326	0.014

[a] One band equivalent to a change in length of 0.00001156615 in.

[b] One division corresponds to 0.001 radians rotation of the lozenge, equivalent to strain of 0.0002 with a 0.2 in. lozenge over a 1-in. gage length.

[c] Calculated changes in autocollimator reading computed from the least squares line:

Autocollimator reading = −0.0105 + 0.0581522 × no. of bands

It is customary to take several sets of readings such as those given in Table I in calibrating a gage. Readings are taken for both increasing and decreasing gage lengths. For each run the calibration factor of the gage and autocollimator is calculated by dividing the change in length corresponding to one band, 0.00001156615 in., by the product of the gage length and the slope of the least squares line. The results of six runs on the same gage are given in Table II. The maximum percentage deviation from the average factor is 0.08 per cent. The maximum difference between observed and calculated changes in autocollimator readings is 0.024 division. For five of the six runs the maximum difference between observed and calculated readings is less than one vernier division (0.02 division).

TABLE II.—REPRODUCIBILITY OF RESULTS FOR A TYPICAL TUCKERMAN STRAIN GAGE.

Gage length 1 in., lozenge diagonal 0.2 in.

Run	Gage Length	Calibration Factor	Deviation From Average Calibration Factor	Percentage Deviation From Average Factor	Maximum Difference Between Observed and Calculated Changes in Autocollimator Readings, divisions[a]
No. 1...	Lengthened	1.9884	−0.00025	−0.01	0.012
No. 2...	Shortened	1.9884	−0.00025	−0.01	0.016
No. 3...	Lengthened	1.9889	0.00025	0.01	0.017
No. 4...	Shortened	1.9902	0.00155	0.08	0.024
No. 5...	Lengthened	1.9886	−0.00005	0.00	0.018
No. 6...	Shortened	1.9874	−0.00125	−0.06	0.014

Average calibration factor = 1.98865

[a] Calculated changes in autocollimator readings computed from equations for least squares lines for each run. One vernier division is equal to 0.02 autocollimator divisions which is equivalent to a strain of 0.000004 in. per inch for a 0.2 in. lozenge over a 1-in. gage length.

Experience in calibrating a large number of gages indicates that the maximum departure of the readings from linearity when calibrated over this range seldom exceeds 0.025 divisions. When the calibration range is reduced to about 22 autocollimator divisions (one scale length), the maximum departure from linearity seldom exceeds 0.015 divisions.

The range of calibration used in determining the effects on the calibration factor of variations in mounting force, material, position, and temperature was about 20 autocollimator divisions (350 interference bands). For each run eight autocollimator readings were taken corresponding to eight equally spaced settings of the calibration device. The calibration factor for each run was computed from the slope of the least squares line.

Effect of Seating of the Lozenge:

During the calibration of a Tuckerman strain gage the lozenge may be turned through an angle greater than the range of calibration in an effort to seat it without disturbing the alignment of the gage on the calibration device. In attaching the gage to a specimen or structure it is difficult to seat the lozenge by this method. To determine the variation in calibration factor with the seating of the lozenge, a gage having a gage length of 1 in. and a 0.2-in. lozenge was calibrated on 9 different materials having Vickers numbers ranging from about 10 to 800. The maximum difference between the calibration factor for the initial rotation of the lozenge and the calibration factor for the twentieth rotation of the lozenge was 0.05 per cent for metals and 0.1 per cent for plastic materials for a mounting force of 1 lb. These values are very much less than the variations of 1 to 5 per cent reported by Vose[2] for the Huggenberger tensometer. This is probably due, as was pointed out by Tuckerman in his discussion of Vose's paper, to the greater stiffness of the lozenge and the greater included angle at its edge.

Effect of Mounting Force:

The variation of the calibration factor of a gage with mounting force was determined by calibrating the gage on various materials with mounting forces varying from the weight of the gage (1 oz.) to 20 lb. The results for two materials, celluloid and duralumin, are given in Fig. 5. The deviation of the observed factor from the average factor for a number of materials having Vickers numbers from about 10 to 800 for a mounting force of 1 lb. is plotted as the ordinate.

The slight increase in factor shown for a mounting force of only the weight of the gage over the factor for a mounting force of 1 lb. may be attributed to slight slipping of the gage. More consistent results were obtained with a mounting force of 1 lb. than for any other force used. For static tests there is no necessity to use mounting forces in excess of about 1 lb. It is unlikely, however, that excesssive force would actually be used in testing materials such as celluloid since so large an amount of creep is observed after the application of forces of 10 and 20 lb. that no reliable readings can be obtained until sufficient time has elapsed for the rate of creep to become negligible.

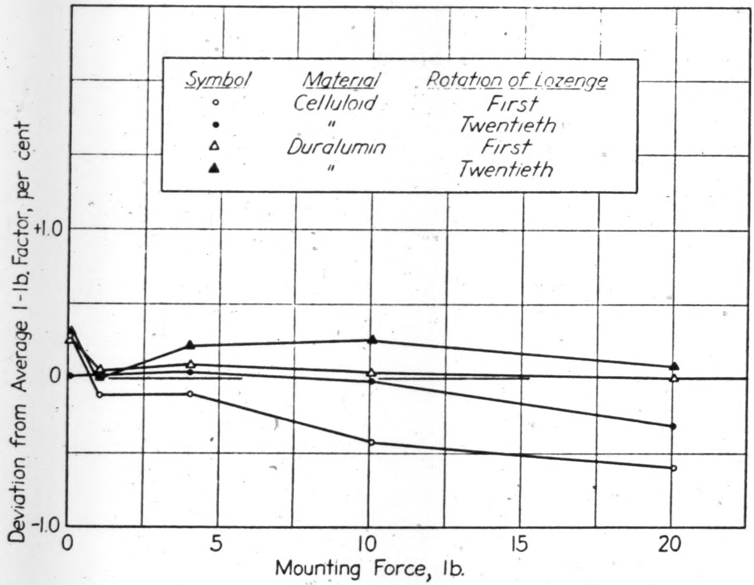


FIG. 5.—Variation of Calibration Factor with Mounting Force.

The maximum variation of calibration factor with mounting force (0.6 per cent) was obtained on celluloid. For celluloid the calibration factor with mounting forces greater than 4 lb. is less than the factor for 1 lb. while for duralumin the factor is greater than the factor for 1 lb. In addition to the results shown in Fig. 5, tests were made on spring steel (Vickers number 545) with both 1- and 2-in. gage length gages having 0.2-inch lozenges. The maximum difference between the factor for 1 lb. and the factor for 20 lb. was 0.25 per cent.

It is desirable that the mounting force be applied by means of low spring constant springs so that the force will not vary greatly during a test, since the reading of the gage varies with the mounting force because of deformation of the gage body and knife-edge.

Effect of Material:

The variation of the calibration factor with material of the specimen for a 1-lb. mounting force is shown in Fig. 6. The maximum deviation of an individual factor from the average factor is less than 0.14 per cent for an organic plastic material. The maximum deviation for metallic specimens is 0.12 per cent. The Vickers number of the Stellite of which the lozenge is made is somewhat less than 777.

Effect of Position:

The calibration factors of a typical 1-in. gage for five different positions are given in Table III. In each position the gage was attached to steel spindles (Vickers number 187) with a spring force of approximately 1 lb. The maximum percentage deviation from the average is 0.06 per cent. This difference is not believed to be significant since variations as great as this are observed in repeated calibrations of a given gage in the same position.

Effect of Temperature:

A 1-in. gage was calibrated at constant temperatures of 70 F. and 100 F. to determine the variation of the calibration factor with temperature. Eight runs were taken at each temperature. The average factor for 100 F. was 0.05 per cent greater than the average factor for 70 F. This value is not believed to be significant.

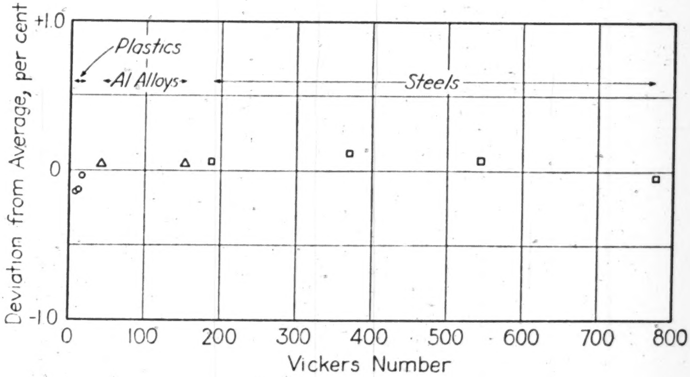


FIG. 6.—Variation of Calibration Factor with the Material of the Specimen for a Mounting Force of 1 lb.

TABLE III.—VARIATION OF CALIBRATION FACTOR WITH POSITION OF GAGE.

Gage Axis	Lozenge Axis		Calibration Factor	Deviation from Average Calibration Factor	Percentage Deviation from Average Factor
Horizontal	Horizontal	Gage above spindles	1.9874	0.0001	0.01
Horizontal	Horizontal	Gage below spindles	1.9884	0.0011	0.06
Horizontal	Vertical		1.9862	−0.0011	−0.06
Vertical	Horizontal	Lozenge up	1.9877	0.0004	0.02
Vertical	Horizontal	Lozenge down	1.9866	−0.0007	−0.04
Average........................			1.9873		

Accuracy and Sensitivity:

Calibration results reported indicate that the calibration factor for an individual run may differ from the average calibration factor for a number of runs by almost 0.1 per cent. These deviations are probably due to variations in the seating of the lozenge which result in different effective lengths of the lozenge diagonal. Since the modulus of elasticity is inversely proportional to the calibration factor used in computing the indicated strain, variations as great as 0.1 per cent are to be expected in determinations of the modulus of elasticity.

The results reported indicate that the readings of the autocollimator are proportional to the change in length of the gage length of the gage to about one vernier division (4×10^{-6} in.) for a range of calibration of 0.010 in. For the 1-in. gage length gage used in the tests reported, for a range of calibration of 0.004 in., less than 3 per cent of more than 750 readings differed from the least squares lines by more than $\frac{1}{2}$ vernier division (2×10^{-6} in.). More than 60 per cent of the readings differed by less than $\frac{1}{4}$ vernier division (1×10^{-6} in.). The maximum variation was 1.4 vernier divisions.

All the results reported were obtained in a temperature-controlled room. For variable temperatures the readings of the autocollimator will change because of unequal expansion of the specimen and the body of the gage. Even if the coefficients of linear thermal expansion of the specimen and gage bodies are equal, in general the cross-sectional areas are unequal, and there is a differential rate of expansion or contraction which results in a shift of reading due to temperature. To avoid this source of error it is necessary to wait until temperature equilibrium is established after the gages and specimen are handled, and then to maintain the specimen and gages at a constant temperature during tests. Unfavorable temperature conditions may introduce errors much greater than any of the variations reported.

CONCLUSIONS

The readings of a Tuckerman strain gage are proportional to the change in length of the gage length to about 1 vernier division.

Mounting forces of 20 lb. produced changes in calibration factor as great as 0.6 per cent. For non-vibrating tests most satisfactory results were obtained on all materials with a mounting force of about 1 lb. This should be applied with low spring constant springs to minimize changes in mounting forces during a test.

If a mounting force of about 1 lb. is used, probably the most satisfactory material for the spindles of the calibration device would be a metallic material having a Vickers number in the neighborhood of 150 to 200.

The position of the gage in space has no significant effect on the calibration factor.

For constant temperatures within the range 70 to 100 F. the calibration factor is independent of temperature.

FACTORS AFFECTING HARDNESS RELATIONSHIPS IN THE RANGE 50 TO 250 BRINELL

By Robert H. Heyer[1]

Synopsis

This paper is a continuation of previously reported work of the author which was undertaken to assist the Joint A.S.M.–A.S.T.M.–S.A.E. Committee on Hardness Conversions in its study of hardness conversions for metals below about 250 Brinell (0 to 100 Rockwell B scale).

Data are presented to show the effect of work-hardening capacity and the importance of close control of time of load application. A method based on observation of the contour of hardness indentations is described for constructing general hardness conversion tables of improved accuracy. Certain hardness – tensile strength relationships given in the literature are considered from the standpoint of the author's experimental data.

A testing procedure is suggested for establishing both hardness and tensile conversion tables for specific materials.

Reliable hardness conversions for soft steels and the non-ferrous alloys are needed. The Joint A.S.M.-A.S.T.M.-S.A.E. Committee on Hardness Conversions[2] has investigated the problem and concluded that the relationship between two hardness scales cannot, in this range, be expressed by a single function, and that specially determined conversion relationships will be necessary for specific materials.

The committee is also aware of the need for improved hardness – tensile strength relationships in the hardness range under consideration and proposes to include tension tests in future investigations.

In a recent paper (**1**),[3] the author presented data which served to outline some of the problems involved in hardness conversions. This work has now been extended to include tension test results and standard Brinell tests. Test methods for determining conversion relationships will be described and recommendations made for a definite procedure that can be followed in laboratories that may wish to cooperate in furnishing additional data to the committee. Another purpose of this paper is to present a plan for improving the accuracy of conversions using data now available.

Materials

In the previously reported investigation, many of the test specimens were of sheet thicknesses too thin for Brinell tests. Baby Brinell data were obtained from Rockwell impressions made with a $\frac{1}{16}$-in. diameter ball. While these data illustrate certain features of Brinell compared with Rockwell and Vickers diamond pyramid hardness (D.P.H.) readings, they only approximate standard 10-mm. ball Brinell results. Additional materials ¼-in. thick and also in the form of round bars have been tested. The ¼-in. flat-rolled material is best suited for this work, therefore, it was more completely investigated than the round bars.

---

[1] Supervisor, Metallurgical Laboratory, The American Rolling Mill Co., Middletown, Ohio.

[2] This committee has functioned under the Section on Indentation Hardness of A.S.T.M. Committee E-1 on Methods of Testing.

[3] The boldface numbers in parentheses refer to the reports and papers appearing in the list of references appended to this paper, see p. 1044.

TABLE I.—ADDITIONAL HARDNESS DATA FOR SAMPLES PREVIOUSLY TESTED (1).

Specimen	Diamond Pyramid Hardness, D.P.H., Avg. 30 and 50 kg.	Rockwell B scale	Brinell Hardness				Meyer		Type of Indentation
			500 kg.	1500 kg.	3000 kg.	d = 3.75 mm.	"a"	"n"	
A1	122.5	65.6							Ridging
A3	94.1	37.7							Ridging
A4	112.3	56.6							Ridging
C1	114.0	60.1	102	95	89[a]	98	83	1.97	Ridging
C3	120.2	65.0							Ridging
C7	106.7	57.4							Ridging
B1	72.8	29.9	67	75	76[a]	70.5	38	2.31	Sinking
B2	79.7	37.0	72	80.5	82[a]	77	43	2.29	Sinking
B3	92.9	50.0							Sinking
B4	103.1	57.4	95	103	106	101	59	2.25	Flat
B5	121.5	70.2	115	121	123	119.5	78	2.17	Flat
B6	59.5	6.9	56.5	63	67[a]	58.5	29	2.38	Sinking
S1	82.2	40.4							Flat
S2	72.0	26.4							Sinking
S3	68.0	23.2							Sinking
S4	74.6	37.0							Sinking
S5	71.5	33.3							Sinking
S6	73.0	31.2							Sinking
M1	63.0	21.5	63	70	70[a]	66	38	2.28	Sinking
D2	124.2	69.1	116	116	112	117	88	2.07	Ridging
D3	77.7	14.0	72	66.5	59.5[a]	70	59	1.98	Ridging
D4	79.5	23.4							Ridging
D5	75.7	17.6	71						Ridging
D6	70.1	6.6	66	59	[b]	64	56	1.95	Ridging
D7	83.3	26.6	81	76.5	69[a]	79.5	67	1.985	Ridging
MM1	118.7	67.8							Sinking
CB1	124.8	68.7	111	115	116[a]	115	76	2.16	Ridging
CB2	158.5	83.5	144	147	148[a]	146.5	105	2.115	Ridging
CB3	169.5	87.9	158	162	166[a]	163	111	2.14	Ridging
CB4	187.3	91.5	169	173[a]	174[a]	173.5	125	2.11	Ridging
CB5	194.0	93.5	177	183[a]	187[a]	184	127	2.13	Ridging
CB6	86.4	43.8	76	81[a]	82[a]	79.5	48	2.25	Flat
CB7	78.3	34.5							Sinking
CB8	61.7	12.0							Sinking
SS1	217.7	95.0							Flat
SS2	155.1	80.8							Flat
SS4	160.8	82.4							Sinking
SS5	147.6	78.4	117						Sinking
SS6	154.5	81.7	125	134[a]	140[a]	136	84	2.21	Flat
SS10	139.4	74.5	106	125	135[a]	122	59	2.40	Sinking
SS11	172.2	86.2	135	152	161[a]	153	85	2.31	Sinking
SS12	180.5	90.3	155	169	170[a]	167.5	108	2.185	Flat
SS14	235.7	99.9	208	227	236[a]	234	145	2.22	Flat
SS30	136.6	73.0	107	120[a]	131[a]	119	63	2.35	Sinking
SS31	167.4	83.4	131	146	156[a]	148	82	2.30	Sinking
SS33	252.2	99.8	202	214	228[a]	224	140	2.21	Flat
SS60	143.1	75.2							Flat
SS61	158.5	81.2							Flat
SS62	176.5	87.3							Flat
SS63	194.2	92.4	177	174	170[a]	172	137	2.03	Ridging

[a] Diameter of indentation extrapolated from the Meyer load-diameter relationship. All Brinell readings in the column $d = 3.75$ mm. are for diameters interpolated from this relationship.

[b] Indicated diameter of indentation greater than 7.0 mm.

All materials were commercially available alloys. Their composition or trade name and the processing treatments are given in Tables I, II, and III. Additional data for the materials listed in Table I will be found in the earlier publication on this subject (1).

TEST METHODS

Many of the materials of the earlier investigation were thick enough for Brinell tests. However, in some cases only 500-kg. tests could be made and in others the maximum load was 1000 or 1500 kg. In the latter case tests were also made at 300, 500, 1000, and 1500 kg. to establish the Meyer hardness relationship, from which the 3000-kg. Brinell hardness could be calculated with good accuracy.

All of the new materials were tested at five or six loads to establish the Meyer hardness relation. No impressions larger than about 5.5 mm. diameter were made. The Brinell hardness at 3000 kg. was determined from the Meyer relationships, however, if the diameter indicated by the extrapolated load-diameter line was less than 7.0 mm. All of these tests were made in an Amsler universal testing machine using a 10-mm. tungsten carbide ball. The maximum calibration error in the 10,000-lb. range used was +0.4 per cent. The load was applied at a moderate rate and maintained for 30 sec. The method of concentric indentations was used for successive loadings in the Meyer hardness procedure. The diameters of the impressions were measured to ±0.01 mm. with a micrometer slide comparator type Brinell microscope at a magnification of 40.

Rockwell tests were made on Rockwell hardness testers calibrated against standard blocks. A steel pedestal or spot anvil was used. In the case of the $\frac{1}{4}$-in. flat-rolled material, special care was taken to reduce experimental error. Blocks 2 by 3 in. were prepared by machine and hand grinding on abrasive papers down to No. 0 grade. They were ruled into 10 equivalent zones for Rockwell and Vickers determinations. The Rockwell readings were corrected for the small deviation of the machine from standard block readings.

The testing procedure recommended in A.S.T.M. Standard Methods of Test for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials (E 18 – 42)[4] was followed. A second set of readings was made using the procedure given in the Wilson Mechanical Instrument Co. instruction book and widely copied in handbooks, pamphlets, and in recent books on hardness testing. The difference in these procedures is in time of load application. According to Methods E 18, the major load should be removed "when the pointer suddenly slows down" or "the moment it is seen that the major load is fully applied." According to the manufacturer of the Rockwell tester, the major load should be removed when the pointer "comes to rest." It was found that the elapsed time by the first method varied from 5.3 sec. at 39 Rockwell B scale to 3.8 sec. at 96 Rockwell B scale. (Free loading time was set at 5 sec. with the machine set up to apply a major load of 100 kg.) A total elapsed time of 15 sec. was established for the second method. In most cases the movement of the pointer was imperceptible or very slow at the end of this period.

The standard deviation based on ten readings was calculated for all Rockwell and Rockwell Superficial data for the $\frac{1}{4}$-in. flat-rolled materials.

Diamond pyramid hardness (D.P.H.) tests were made on a Vickers hardness

---

[4] 1942 Book of A.S.T.M. Standards, Part I, p. 915.

TABLE II.—HARDNESS DATA.

Specimen	Material	D.P.H. 50 kg.	Rockwell Hardness												Brinell Hardness				Meyer *a*	Meyer *n*	Type of Indentation
			G Scale		B Scale		F Scale		45-T Scale		30-T Scale		15-T Scale								
			A.S.T.M.	15-sec.	A.S.T.M.	15-sec.	A.S.T.M.	15-sec.	A.S.T.M.	15-sec.	A.S.T.M.	15-sec.	A.S.T.M.	15-sec.	500 kg.	1500 kg.	3000 kg.	d = 3.75 mm.			
¼-In. Flat-Rolled Materials																					
C8	Copper cold-rolled	110 std. dev.	....	....	54.6 0.64	51.5 0.73	91.6 0.45	89.9 0.50	37.4 1.12	35.1 0.77	60.0 0.89	58.9 0.74	82.5 0.38	81.9 0.42	99	91.5	83^b	88.5	83	1.95	ridging
B7	Brass, cold rolled	189 std. dev.	....	66.9 0.81	....	90.6 0.44	....	108.1 0.41	....	63.0 0.60	....	76.1 0.51	....	89.5 0.38	174	180	178	177	127	2.095	ridging
B8	Brass, cold rolled, 850 F. anneal	77 std. dev.	....	....	39.9 0.69	39.3 0.47	80.5 0.32	....	12.6 0.68	12.3 0.51	42.4 0.59	42.3 0.38	73.4 0.19	73.4 0.28	72	81	82.5^b	77	43	2.31	sinking
S7	Ingot iron	71 std. dev.	....	....	30.6 0.53	24.4 0.56	74.8 0.74	70.8 0.44	103.9 0.65	98.1 0.93	37.6 0.66	33.3 0.73	71.0 0.56	69.0 0.60	66	71.5	73.5^b	68.5	37	2.31	sinking
S8	0.18 per cent carbon steel, cold rolled	223 std. dev.	76.4 0.42	74.9 0.36	96.0 0.51	95.2 0.40	110.8 0.16	110.5 0.13	68.0 0.44	67.4 0.57	79.8 0.43	79.2 0.72	91.7 0.20	91.4 0.31	204	207	207	202	166	2.00	ridging
S9	0.18 per cent carbon steel, 1600 F. anneal	123 std. dev.	....	....	70.1 0.26	68.4 0.33	96.3 0.12	95.5 0.16	42.4 0.23	41.1 0.37	61.7 0.36	60.9 0.36	82.6 0.23	81.9 0.10	107	114.5	117	112.5	71	2.22	flat
S10	0.18 per cent carbon steel, 1600 F., air cooled	136 std. dev.	46.0 0.87	42.0 0.21	76.3 0.34	74.9 0.39	99.7 0.26	98.9 0.35	48.0 0.51	46.1 0.32	65.9 0.52	64.8 0.33	84.7 0.39	84.2 0.30	120	126.5	130	126.5	82	2.18	flat
S11	0.18 per cent carbon steel, normalized plus 1300 F. anneal	130 std. dev.	....	....	73.2 0.88	71.5 0.56	98.2 0.33	97.2 0.20	46.1 0.47	44.4 0.40	64.2 0.25	64.1 0.36	83.5 0.28	83.0 0.37	114	119.5	123	119	77	2.17	flat
D8	Alcoa 24ST	146 std. dev.	46.9 0.60	46.4 0.37	77.7 0.17	77.2 0.07	100.8 0.22	100.7 0.23	50.8 0.57	50.2 0.51	68.3 0.32	68.1 0.20	86.2 0.29	86.0 0.30	130	139	144	139	88	2.185	flat
SS7	19.5 per cent chromium, 9.5 per cent nickel steel	153 std. dev.	53.4 0.63	50.9 0.64	80.0 0.50	77.9 0.74	100.9 0.27	99.5 0.27	49.1 0.44	46.9 0.41	67.0 0.53	65.0 0.49	84.8 0.35	83.8 0.25	121	134.5	145	136	71	2.35	sinking

ROUND BARS

	Alcoa:																				
A5	2SH	...	....	....	[a]	....	....	....	....	....	....	....	....	....	....	....	....	....	30.5	2.025	ridging
A6	2SO, 600 F. anneal	....	....	....	[a]	....	....	....	....	....	....	....	....	....	....	....	....	....	13	2.245	flat
	Herculoy, silicon bronze:																				
B9	As received	242	....	....	101.1	....	....	....	....	....	....	....	....	....	222	222	223	224	165	2.08	ridging
B10	550 F. anneal	120	....	....	68.2	....	....	....	....	....	....	....	....	....	106	114.5	120	114	68	2.24	sinking
B11	850 F. anneal	80	....	....	38.0	....	....	....	....	....	....	....	....	....	71	83	89	78.5	35	2.44	sinking
	0.19 per cent carbon steel:																				
S12	cold rolled	181	....	....	90.2	....	....	....	....	....	....	....	....	....	175	170	167	170	136	2.00	ridging
S13	1300 F. anneal	126	....	....	70.4	....	....	....	....	....	....	....	....	....	110	114.5	114	114.5	78	2.13	flat
S14	1600 F. anneal	115	....	....	65.2	....	....	....	....	....	....	....	....	....	104	107.5	106	106.5	75	2.11	flat
	Dowmetal F:																				
M2	As received	....	....	....	[a]	....	....	....	....	....	....	....	....	....	....	....	....	....	18.5	2.57	sinking
M3	750 F. anneal	....	....	....	[a]	....	....	....	....	....	....	....	....	....	....	....	....	....	18.2	2.56	sinking
M4	Dowmetal A, as received	61.5	....	....	20.6	....	....	....	....	....	....	....	....	....	58.5	68.5	74.5	61	25	2.52	sinking
	Alcoa:																				
D9	51SH	....	....	....	[a]	....	....	....	....	....	....	....	....	....	....	....	....	....	28.5	2.17	flat
D11	51ST, ppt. at 300 F.	97.5	....	....	51.2	....	....	....	....	....	....	....	....	....	86.5	87	85.5	88	61	2.11	ridging
D12	51SO, 800 F. anneal	....	....	....	[a]	....	....	....	....	....	....	....	....	....	....	....	....	....	16.5	2.195	flat

[a] These materials are softer than 0 Rockwell B Scale.

[b] Diameter of indentation extrapolated from the Meyer load-diameter relationship. All Brinell readings in the column $d = 3.75$ mm. are for diameters interpolated from this relationship.

tester using a 50-kg. load. (The data from the earlier paper include 30-kg. tests.) The timing was set for 20 sec. total elapsed time for the loading and unloading cycle.

TABLE III.—TENSION DATA.

Specimen	Yield Strength, 0.5 per cent effect, psi.	Tensile Strength, psi.	Elongation in 2 in., per cent	Reduction of area, per cent	$\frac{\text{Yield Point (0.5\%)}}{1810 \times a}$	$\frac{\text{T.S.}}{1810 \times a}$	$\frac{\text{Y.S. (0.5\%)}}{\text{T.S.}}$	t	m	s
					¼-IN. FLAT-ROLLED MATERIAL[a]					
C8	47 250	47 350	11.0	58.9	0.314	0.315	0.999	0.010	∞	0.425
B7	76 600	79 450	13.0	52.5	0.333	0.346	0.965	0.043	30.0	0.855
B8	21 400	51 450	59.8	70.7	0.275	0.660	0.417	0.296	3.82	0.835
S7	23 800[b]	38 800	53.5	82.1	0.356[b]	0.580	0.613[b]	0.219	5.36	0.60
S8	99 300	100 000	11.8	53.6	0.331	0.332	0.993	0.010	∞	0.66
S9	40 600[b]	59 150	39.5	67.4	0.316[b]	0.461	0.686[b]	0.185	6.62	0.645
S10	46 100[b]	67 600	36.3	69.0	0.311[b]	0.456	0.682[b]	0.183	6.47	0.76
S11	44 900[b]	61 600	41.0	75.9	0.322[b]	0.442	0.728[b]	0.174	6.72	0.735
D8	49 900	69 650	20.5	28.6	0.313	0.438	0.715	0.180	5.68	0.70
SS7	40 200	84 000	61.8	68.9	0.313	0.654	0.479	0.242	4.92	1.31
					ROUND BARS[c]					
A5		20 750	21.0	71.2		0.376				
A6	5 720	12 130	46.4	83.0	0.243	0.516	0.472			
B9	115 000	120 100	13.0	45.8	0.385	0.402	0.956	0.030	37	0.84
B10	34 000	68 250	59.0	65.4	0.276	0.552	0.498	0.235	4.7	0.84
B11	16 100	57 950	74.9	79.4	0.253	0.909	0.278	0.372	2.9	0.80
S12	77 250[b]	79 120	19.4	58.7	0.314	0.322	0.975	0.045	22.9	0.95
S13	39 500	59 230	43.1	77.5	0.281[b]	0.420	0.670[b]	0.192	5.8	0.66
S14	30 000[b]	54 950	42.8	62.6	0.221[b]	0.405	0.546[b]	0.245	4.5	0.54
M2		38 000	11.0	16.0		1.135				
M3	28 700	36 700	12.8	20.8	0.872	1.112	0.782	0.117	9.0	0.28
M4	36 670	48 000	11.0	14.8	0.810	1.06	0.764	0.133	8.7	0.18
D9	22 550	22 830	16.0	59.2	0.437	0.443	0.985	0.027	41.7	0.15
D11	38 570	43 730	20.3	41.4	0.349	0.396	0.880	0.090	14.4	0.29
D12	9 330	14 830	40.4	70.6	0.312	0.496	0.626	0.178	7.0	0.17

[a] All tensile tests are average of duplicate samples.
[b] Based on lower yield point.
[c] Tensile data are average of 2 or 3 tests of 0.505-in. diameter specimens.

Tension tests were made on 2-in. gage length specimens $\frac{1}{4}$ by $\frac{1}{2}$ in. in section for the flats and 0.505 in. in diameter for the round bars. An Amsler testing machine and a Kenyon-Burns-Young wedge type extensometer were used. Autographic load-extension curves were obtained at 10 times strain magnification.

The load at fracture was noted so that true stress-strain curves could be derived from the data according to the method of MacGregor (2). The area at fracture of the rectangular specimens was obtained from readings made with a micrometer having conical tips. If t_1 and t_3 are thickness readings at the corners, t_2 is the thickness at the mid-point, and w is the average width of the section, the final area is assumed to be

$$\frac{W}{6}(t_1 + 4t_2 + t_3)$$

The true area at intervals up to the maximum load point was obtained from the corresponding elongation readings as measured from the load extension curve, applying the principle of constant volume. From the calculated true area and the indicated load, the true stress was obtained. The abscissa of the derived stress-strain curve was taken as $ln\ \frac{A_o}{A}$ where A_o is the initial area and A the instantaneous true area. The slope of the line drawn from the fracture point

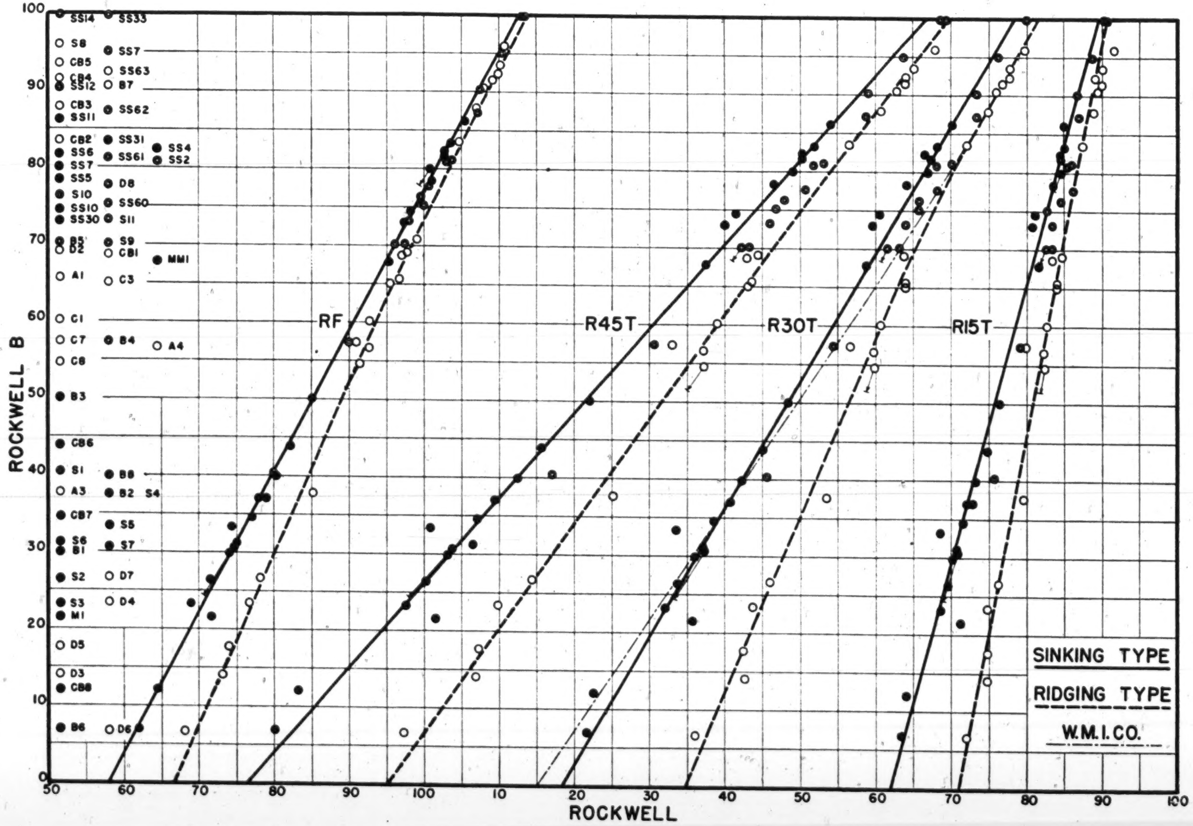


FIG. 1.—Rockwell B *versus* Rockwell F and Rockwell Superficial Hardness Scales.

tangent to the calculated portion of the curve was taken as a measure of the work-hardening rate (*s* in Tables II and III).

Another type of stress-strain curve was plotted using the logarithm of the true stress and the logarithm of the percentage elongation, in the manner described by Kokado (3) and Schwarz (4). This treatment of the data tends to straighten the plastic portion of the curve up to the maximum load point. The cotangent of the resulting line is considered to be a measure of the rate of work-hardening (*m* in Tables II and III). The average slope of the plastic line or curve was taken as another measure of the rate of work-hardening (*t* in Tables II and III). The cotangents and tangents, *m* and *t*, were measured over the increments 1 to 2, 2 to 3, 3 to 4, 4 to 5, 5 to 7, 7 to 10, 10 to 15, and 15 to 20 per cent elongation but not beyond the maximum load point.

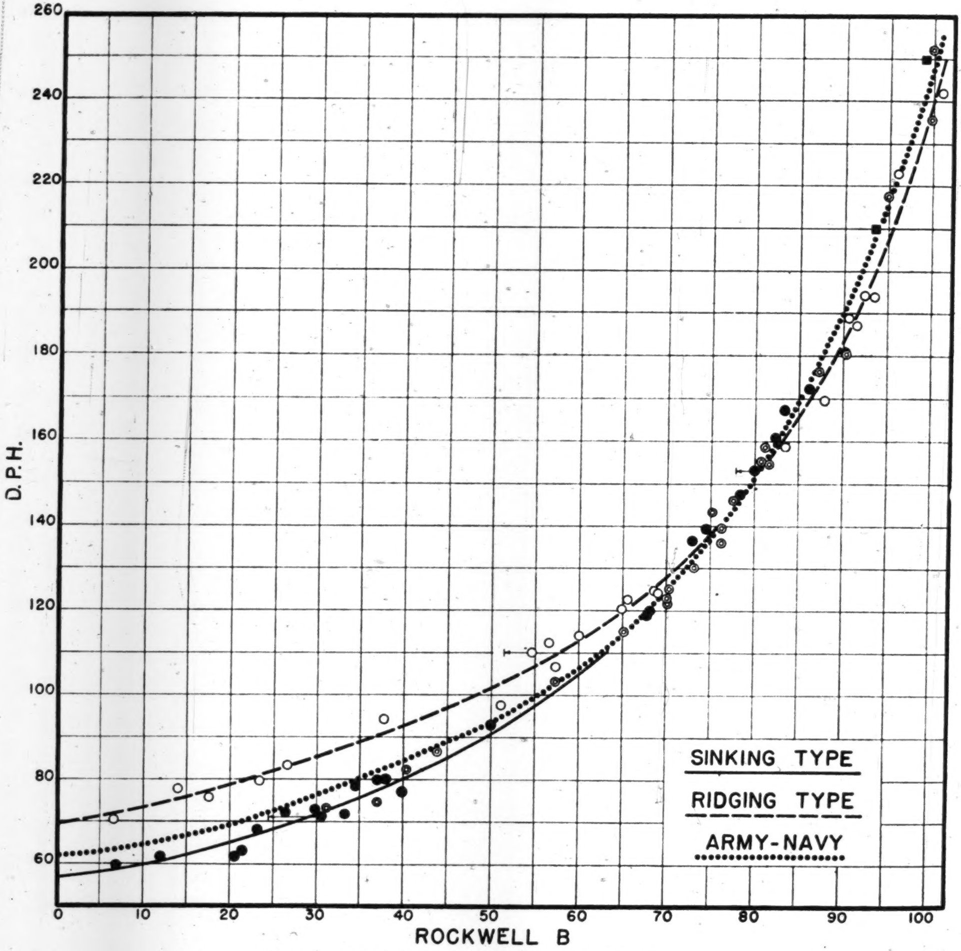


FIG. 2.—D.P.H. *versus* Rockwell B Hardness.

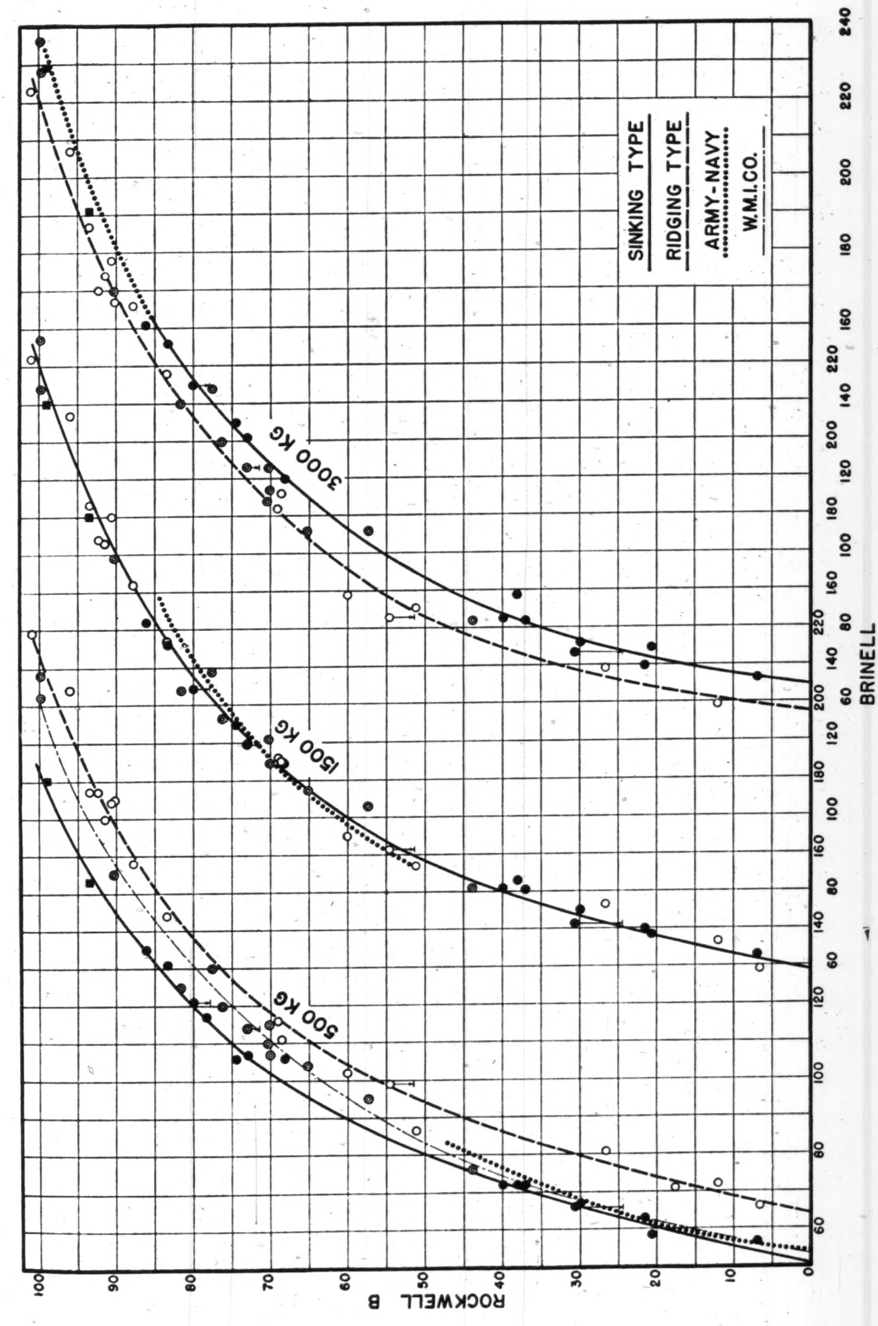


FIG. 3.—Rockwell B *versus* Brinell Hardness.

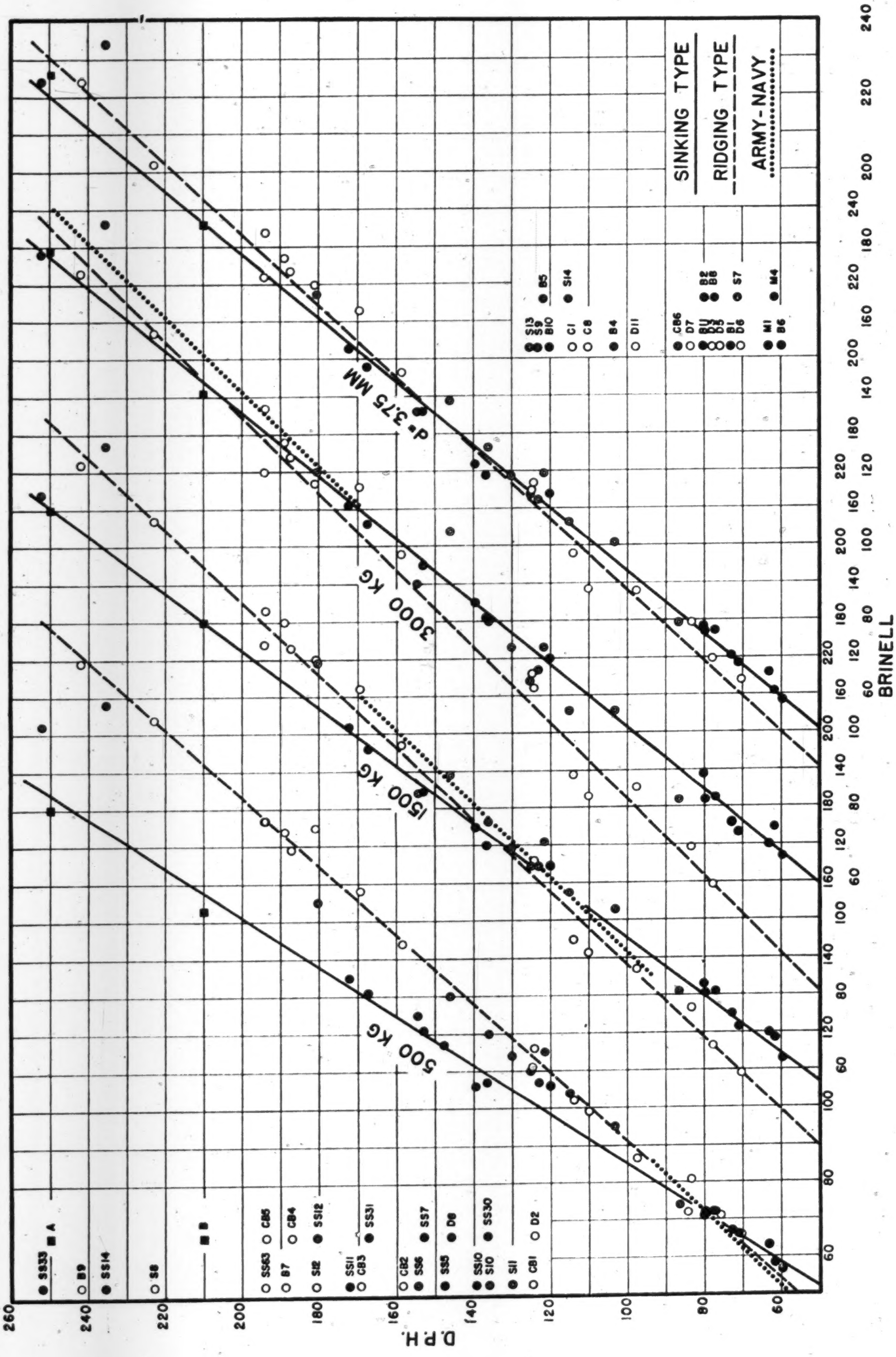


FIG. 4.—D.P.H. *versus* Brinell Hardness.

DISCUSSION OF DATA

The principal hardness conversion relationships are plotted in Figs. 1 to 4. Figs. 1 and 2 are similar to Figs. 6 and 5 of the earlier paper and are based on the same data, with the addition of points representing the $\frac{1}{4}$-in. flat-rolled specimens. However, in the present illustrations each point is identified with the appearance of the hardness indentation instead of the Meyer n or work-hardening coefficient. The solid circles represent materials whose hardness indentations are of the "sinking-in" type which is always associated with annealed materials of high work-hardening capacity. The open circles represent "piling-up" or "ridging" type impressions which are associated with cold-worked materials of low work-hardening capacity. This divides the data into two groups representing the extremes of work-hardening capacity and was thought to offer a more practical means of compensation for this effect. The double circles represent

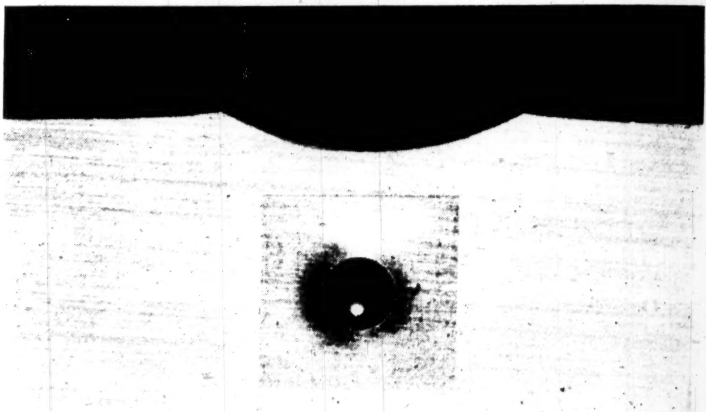


FIG. 5.—Section and Plan of a Ridging Type Brinell Indentation.
The length of the original impression diameter is about 5.1 mm. for the illustrations in Figs. 5 to 8.

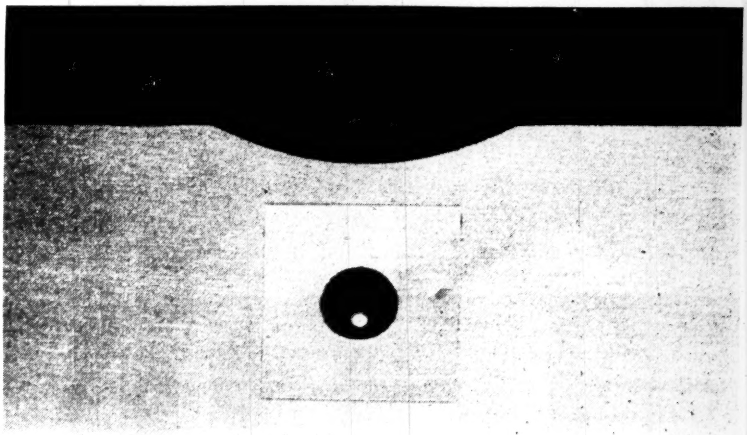


FIG. 6.—Section and Plan of a Flat Type Brinell Indentation.

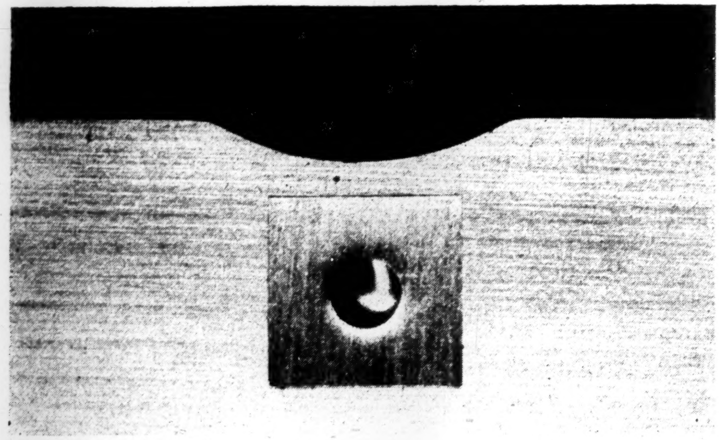


FIG. 7.—Section and Plan of a Sinking Type Brinell Indentation.

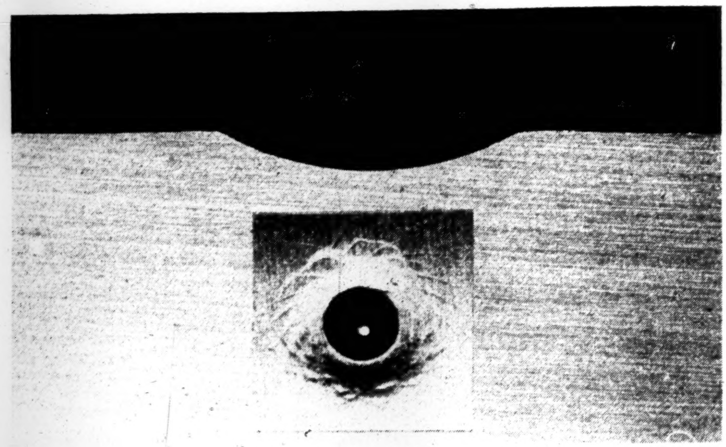
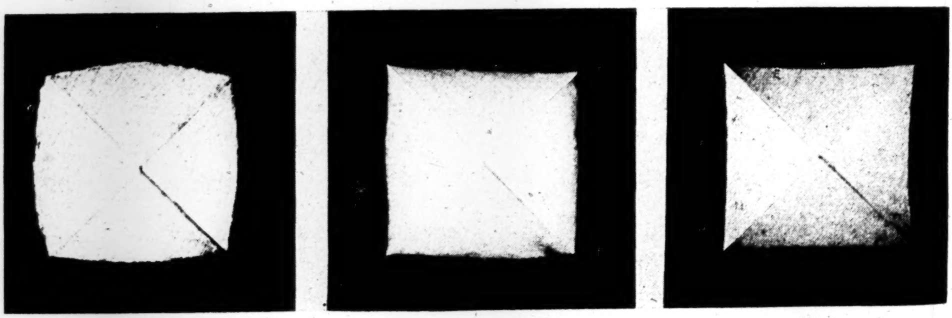


FIG. 8.—Section and Plan of a Brinell Indentation in Annealed Mild Steel.



(*a*) (*b*) (*c*)

FIG. 9.—Vickers (D.P.H.) Indentations in Materials having (*a*) Ridging, (*b*) Flat, and (*c*) Sinking Type Brinell Impressions.

materials having relatively flat hardness indentations which are difficult to classify as either type. In all cases average lines have been drawn through the sinking and ridging points.

The basis for this classification by the appearance of the indentations is shown in Figs. 5 to 9. Some difficulty was experienced in photographing Brinell indentation contours. However, it is not difficult to classify indentations into the three types by inspection of actual samples at an oblique angle. In the case of Rockwell indentations, a low-power lens is useful for close examination. It is desirable to have an impression diameter at least 0.4 times the ball diameter, which may mean making a Rockwell G impression using 150 kg. load in the case of materials having high Rockwell B hardness. Diamond pyramid indentations are somewhat more difficult to classify. The criterion is departure from a true square as shown in Fig. 9.

Irons and steels having appreciable yield point elongation have indentations surrounded by Lüder lines as shown in Fig. 8. In general, steels have indentations which appear, at first, to be of the ridging type. Closer examination reveals that while there has been a general elevation of metal to a considerable distance from the edge of the indentation, the lip tends to be rounded. For the purposes of this investigation such materials are classified as intermediate or flat. In the case of iron or steel heavily cold worked by rolling or drawing, a sharp ridging impression results as in the case of non-ferrous metals. Likewise, dead soft annealed low-carbon drawing grade steels and open-hearth iron may have sinking type indentations.

As an annealed metal is progressively cold worked, the change from a sinking to a ridging type hardness indentation is gradual. Where it is not easily possible to make a decision as to type of indentation, the intermediate classification should be applied. In this investigation, the materials available were, for the most part, either annealed or quite heavily cold worked. It would be desirable to include a more complete selection of tempers in future work on this problem.

It is apparent from Figs. 1 to 4 that reasonably good conversion relationships can be assigned to materials having similar types of hardness indentations. If such relations are used, the average error of conversion can often be greatly reduced compared with that which would result from the use of currently available conversion tables. For example, in Fig. 1, the Wilson Mechanical Instrument Co. Chart No. 38 curve for Rockwell B *versus* Rockwell 30T is satisfactory for sinking type but very inaccurate for ridging type impressions in the range 0 to 60 Rockwell B.

The Army-Navy curves of Figs. 2, 3, and 4 are from the Army-Navy Aeronautical Specification for Heat Treatment of Steels,[7] AN-QQ-H-201. They are represented in the specification as approximate relationships for carbon and low alloy steels. The Army-Navy curves in Figs. 2 and 3 tend to follow the solid and double circles rather than the open circles representing cold-worked materials. Since the specification is limited to structural steels for heat treatment and these would normally be in the annealed or normalized state, it would not be expected that these conversions would apply to work-hardened materials (ridging type impressions). In the D.P.H.-Brinell conversions of Fig. 4, the Army-Navy curves lie parallel to the lines for the ridging type impressions. However, the influence of type of indentation on the conversion relationships is small in the zones covered by the Army-Navy curves.

There is need for more Brinell data to

supplement Figs. 3 and 4, especially the combination of high hardness and high work-hardening capacity. The austenitic stainless steel SS11 at 86 Rockwell B and 172 D.P.H. with Meyer $n = 2.31$ is the hardest material of high work-hardening capacity which was available. Two hypothetical alloys, A and B, were therefore selected having Rockwell and D.P.H. hardnesses consistent with Fig. 2, and D.P.H. and Brinell hardnesses consistent with the 1500 kg. curve of Fig. 4. Both materials were given a Meyer n value of 2.35 representing a high work-hardening capacity. From the relationships between Meyer a and n and the 1500-kg. Brinell values, the 500- and 3000-kg. Brinell values could be calculated. The resulting values are consistent with the extrapolated experimental curves for high work-hardening capacity materials in Figs. 3 and 4. (Materials A and B are plotted as squares in Figs. 2, 3, and 4.) From Fig. 4 it appears that very large errors are possible if any single function is used as a D.P.H. *versus* 500-kg. Brinell conversion curve.

The Rockwell-Brinell conversions of Fig. 3 are particularly significant. For a given Rockwell hardness the spread in 500-kg. Brinell values may vary from 13 to 30 points, the annealed materials with sinking type impressions having the lower Brinell hardnesses. On the other hand, these same annealed materials have, on the average, about 10 points higher Brinell hardness than the cold-worked materials in the 3000-kg. Brinell tests. At the intermediate load of 1500 kg. the Brinell-Rockwell relationship is quite independent of the nature of the material.

The D.P.H.-Brinell relations of Fig. 4 are more complex, although here again the annealed materials of high work-hardening capacity attain relatively higher Brinell hardnesses than the initially cold-worked materials as the load used in the Brinell test is increased. There appears to be some evidence in favor of the 1500-kg. test as the least sensitive to the nature of the material over the hardness range being considered. The data for Brinell hardness at a constant indentation size of $d = 3.75$ mm. show the least scatter of the D.P.H.-Brinell relationships. Unfortunately, it is not possible to make direct hardness determinations at constant indentation size in ordinary Brinell hardness testers.

According to Smith and Sandland (5), the Vickers (D.P.H.) *versus* Brinell values are identical in the range under consideration when the Brinell readings are made at $d = 3.75$ mm. The author's results based on baby Brinell readings tend to confirm this (1) but the 10-mm. ball Brinell values of Fig. 4 are slightly lower than the corresponding D.P.H. values. The difference between these results and those of Smith and Sandland may be due to the use of a tungsten carbide ball in this investigation. Tungsten carbide Brinell balls have obvious advantages at high hardnesses which may lead to their general adoption, hence further information is needed on tungsten carbide *versus* steel balls for Brinell tests on soft as well as on hard metals.

As previously stated, some of the Rockwell tests were made according to both the A.S.T.M. and the Wilson Mechanical Instrument Co. procedures (see Table II). The Rockwell test results plotted in Figs. 1, 2, and 3 are for the A.S.T.M. procedure. In a few instances the reading obtained by the longer time of application of the load is indicated by an arrow extending from the plotted point. In Fig. 1 these arrows lie parallel to the assumed conversion curves showing that no errors in conversion would be introduced provided a consistent testing procedure were used in all Rockwell and Rockwell Superficial tests. In Figs. 2 and 3, it is evident that the longer time of loading can result in either better or worse agreement with the assumed conversion relationships. In any case, the need for agreement on this troublesome point of difference in testing procedure is apparent. The standard deviations obtained by both methods are comparable, the average deviation being 14 per cent higher for the A.S.T.M. method than for the 15-sec. method; therefore, the principal issue is whether the extra time required for the pointer to come to rest is warranted. The time factor is ordinarily under control in D.P.H. and Brinell tests.

Hardness – tensile strength relationships have been obtained for the ¼-in. flat-rolled materials and for a small group of materials in the form of round bars. Preliminary examination of these data indicates that independent relationships based on the appearance of the hardness indentations can probably be applied, as in the case of the various hardness scales. Additional data are needed, however, before suitable curves can be established.

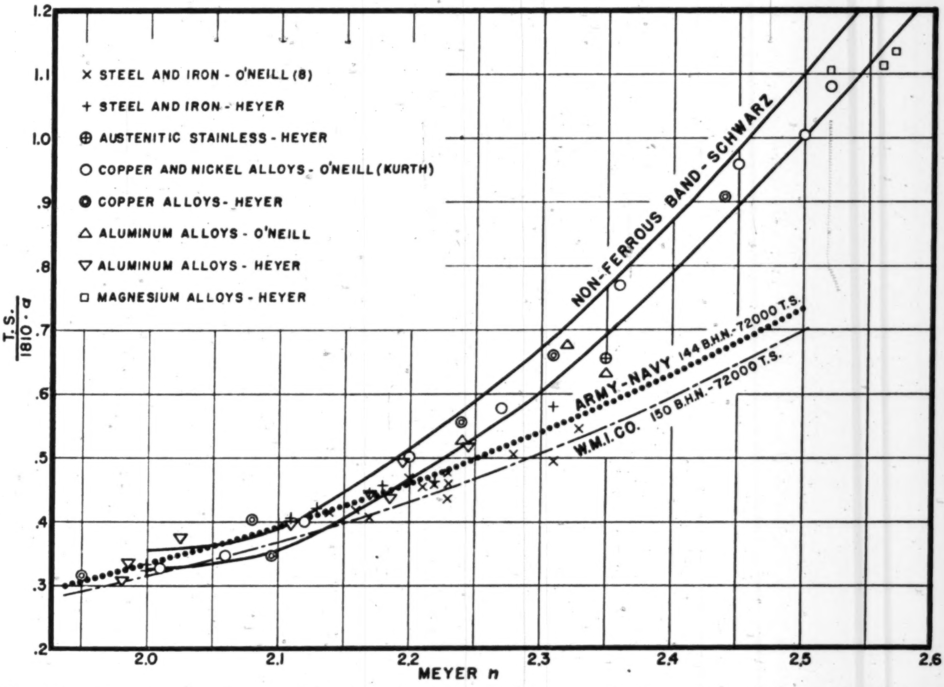


FIG. 10.—Relationship Between the Tensile Strength-Meyer *a* Ratio and the Meyer *n* Coefficient.

Schwarz's data consist of about 50 points in the band between the two solid lines. The tensile strength is expressed in pounds per square inch.

Hardness – tensile strength conversions have been explored by Schwarz (4) who made tension, Brinell, and Meyer hardness tests on a large number of non-ferrous alloys. The relationship between the tensile strength – Meyer *a* ratio and the Meyer *n* work-hardening coefficient which he found to be applicable to his non-ferrous alloys, have been applied to the data obtained by the author and to similar data from the literature, as well as to certain hardness – tensile strength conversions in current use.

As shown in Fig. 10, the data for non-ferrous alloys are in satisfactory agreement with those of Schwarz, while many of the points for steel are nonconforming, falling below the band for the non-ferrous alloys.

The hardness – tensile strength conversion given in Army-Navy Specification AN-QQ-H-201 gives 144 Brinell at 72,000 psi. tensile strength, and the Wilson Chart No. 38 gives 150 Brinell at the same strength. Both are represented as approximate relationships for steel only. For any value of Meyer n which can be assigned, a Meyer a value can be calculated from the Meyer equation which will be consistent with a Brinell hardness of 144 or 150. In this manner curves have been derived for the coordinates of Fig. 10. The Army-Navy hardness – tensile strength relationship for 144 Brinell, for example, is satisfied by a material having a work-hardening capacity (Meyer n) of 2.25 if the corresponding ratio of tensile strength to Meyer a equals 0.50. Similar curves for Brinell – tensile strength relations at other strength levels were drawn and although these were found to differ somewhat from the particular values selected for illustration, it was evident that both the Army-Navy and Wilson Mechanical Instrument Co. conversions fit the data for steels better than the Schwarz band which contains most of the points for non-ferrous metals. For work-hardening capacities less than $n = 2.2$, the ferrous and non-ferrous metals have the same hardness – tensile strength relationships, within the limits of accuracy of this method.

The use of Schwarz's method of estimating tensile strength from hardness is dependent on Meyer hardness data, which requires making indentation diameter measurements at two or more test loads. While this is not always convenient, more use of this test would probably result if the advantages were generally known. Schwarz has presented a short-cut method which makes it unnecessary to determine a or n by either graphical or analytical methods. Two Brinell impressions are made at loads in the ratio of 2 to 1 or 3 to 1 (for example, 3000 and 1500, 2000 and 1000, 3000 and 1000, or 1500 and 500 kg.). From his Fig. 15 the ratio of tensile strength to Brinell hardness can then be obtained. Although this method would not have universal application, preliminary tests by the author indicate that it would be useful if a distinction were made between steels and non-ferrous metals of high work-hardening capacity.

Kokado (3) gave the following relationship for the correlation between the slope of the tension test curve and the Meyer n value:

$$m = \frac{2}{n - 2}$$

where m is the cotangent of the curve for log true stress versus log percentage elongation. The Schwarz data are better described by

$$m = \frac{0.97}{n - 2.06}$$

and the author's data are in substantial agreement, with certain notable exceptions.

Although the work-hardening rates indicated by the tension tests and the Meyer hardness tests are compatible, the relationship is only approximate. It was thought that the work-hardening rate, s, taken from the MacGregor (2) type true stress true strain curve might have a significant relationship to the hardness test. The data reported here do not support this view. In a former study of the Brinell test (6), the author showed that compressive strains seldom exceed 20 per cent under Brinell impressions, therefore one might look for a correlation of the Meyer work-hardening coefficient with the early plastic portion of a compression stress-strain curve, and possibly with the slope *t* of the logarithmic tension stress-strain curve, but not with the portion of the tension curve beyond the maximum load point.

Another approach to the hardness – tensile strength relationship by Peek and Ingerson (7) is based on Rockwell test data. This method also requires hardness readings made at two or more loads (or the use of two or more different size ball indenters). A preliminary study by the author indicated that the method is extremely sensitive to differences of 1 or 2 points Rockwell. Further analysis of this method by its originators, using the data here made available, would be welcome.

CONCLUSIONS

1. Two details of testing procedure should be given further consideration before specific conversion relationships are developed; namely, the control of the time factor in the Rockwell tests, and the influence of tungsten-carbide *versus* ordinary and cold-worked steel balls in the Brinell test.

2. Differences in work-hardening capacity of metals as measured by the Meyer *n* coefficient have a very great influence on hardness and hardness – tensile strength conversion relationships.

3. The marked difference in appearance of ball type hardness indentations depending on the work-hardening capacity of the metal can be used to advantage in selecting conversion relationships of greater accuracy than those now available.

4. Additional test data are needed before the more accurate conversions referred to in conclusion 3 can be made fully effective.

5. The 1500-kg. Brinell test has advantages over the 3000-kg. test in the hardness range under consideration because the size of the indentations is more favorable and the effect of work-hardening capacity on the Rockwell-Brinell conversion relationship is greatly reduced, making it possible to use a single function for this particular conversion.

6. Methods based on appearance of the hardness indentations can probably be used to establish improved hardness – tensile strength relationships when sufficient data become available.

7. The method proposed by Schwarz for obtaining tensile strength from Brinell hardness tests made at two test loads is worthy of further study.

RECOMMENDATIONS FOR OBTAINING HARDNESS AND HARDNESS – TENSILE STRENGTH CONVERSION DATA

1. Flat-rolled stock $\frac{1}{4}$ in. thick or over is preferred over round bars.

2. Variations over the width of the sheet, strip, or plate should be explored by preliminary Rockwell tests to insure uniformity. Material finished by light cold rolling or drawing which may introduce a hardness differential in the thickness direction should be avoided.

3. Chemical inhomogeneity such as surface carburization or decarburization of steels should be avoided.

4. Two hardness test blocks approximately 2 by 3 in. should be prepared and smoothed to grade 1 or 0 abrasive paper by methods which reduce the flow of metal at the surface to a practical minimum. Hand polishing is preferred for the finer abrasive papers. One block may be only roughly finished on one side and the smooth side used for Brinell type tests. The other block

should be smooth on both sides and all Rockwell and D.P.H. tests made on one side. This block should be divided into two banks of five equal rectangles, leaving $\frac{1}{8}$-in. margin at all edges. The various Rockwell, Rockwell Superficial, and Vickers (D.P.H.) tests should be made in each of the ten zones.

5. Rockwell readings should be corrected for deviation of the machine from standard block readings. The tests should conform to A.S.T.M. Standard Methods E 18.

6. The indenter used for Vickers or D.P.H. readings should have an apex angle of 136 ± 1 deg. The loading system of the testing machine should be calibrated:

$$\text{D.P.H.} = \frac{2L \sin \frac{\alpha}{2}}{d^2}$$

where:

d = length of average diagonal in millimeters,

α = apex angle, and

L = load in kilograms.

7. Three Brinell indentations should be made at 500-kg. load, and after measuring the diameter of the indentation, the ball should be reinserted for additional tests at four or five higher loads such as 750, 1000, 1500, 2000, and 3000 kg. In no case should the impression diameter be larger than about 6.0 mm. For very soft metals it is advisable to use an initial load of 300 kg. The load-diameter readings are then plotted on log-log paper and if they fall on a straight line they may be interpolated or extrapolated to 3000 kg. with confidence. However, the 3000-kg. Brinell value should not be used if the indicated impression diameter is over 7.0 mm. The recommendations of A.S.T.M. Standard Method of Test for Brinell Hardness of Metallic Materials (E 10 – 27)[5] should be followed in making Brinell tests.

8. Provision should be made for tension tests using the 2-in. gage length flat specimen of A.S.T.M. Standard Methods of Tension Testing of Metallic Materials (E 8 – 42)[6] for $\frac{1}{4}$-in. thick materials and suitable round specimens for thicker materials. Tension tests would ordinarily be made in the longitudinal direction only. Autographic load-extension curves should be made so that such factors as yield – tensile strength ratio, yield point, elongation, uniform elongation, etc., will be available for analysis if necessary.

Acknowledgment:

The author wishes to thank the members of the Metallurgical Section of the Research Laboratories of The American Rolling Mill Co. for their assistance, and R. L. Kenyon, Chairman of the Joint A.S.M.-A.S.T.M.-S.A.E. Committee on Hardness Conversions, for his guidance and counsel throughout this investigation.

---

[5] 1942 Book of A.S.T.M. Standards, Part I, p. 909.

[6] 1942 Book of A.S.T.M. Standards, Part I, p. 898.

REFERENCES

(1) R. H. Heyer, "Hardness Conversion Relationships," *Proceedings*, Am. Soc. Testing Mats., Vol. 42, p. 708 (1942).

(2) C. W. MacGregor, "The Tension Test," *Proceedings*, Am. Soc. Testing Mats., Vol. 40, p. 508 (1940).

(3) S. Kokado, "Hardness and Hardness-Measurement," *Technical Report*, Tohoku Imperial University, Vol. 6, p. 201 (1927).

(4) O. Schwarz, "Zugfestigkeit und Härte bei Metallen," *Forschungsarbeiten*, p. 313 (1929).

(5) R. L. Smith and G. E. Sandland, "Some Notes on the Use of a Diamond Pyramid for Hardness Testing," *Journal*, Iron and Steel Inst., Vol. 111, p. 285 (1925).

(6) R. H. Heyer, "Analysis of the Brinell Hardness Test," *Proceedings*, Am. Soc. Testing Mats., Vol. 37, Part II, p. 119 (1937).

(7) R. L. Peek and W. E. Ingerson, "Analysis of Rockwell Hardness Data," *Proceedings*, Am. Soc. Testing Mats., Vol. 39, p. 1270 (1939).

(8) Hugh O'Neill, "The Hardness of Metals and Its Measurement," Chapman & Hall, Ltd., London, England (1934).

DISCUSSION

Mr. Vincent E. Lysaght[1] (*presented in written form*).—Mr. Heyer presents a new approach to the old question of conversion charts, and it is possible that anyone experienced in classifying the indentations according to Mr. Heyer's method would be able to get a more accurate estimate of the hardness relation of one scale to another. This would require, however, accurate conversion values for each type of indentation and a large number of tests would have to be made on various materials in different hardnesses, and once these tests are made, it would seem more advantageous and of more value to prepare separate conversion tables for each type of material.

In the laboratories of the Wilson Mechanical Instrument Co., it was found difficult to classify small indentations such as are obtained on the Rockwell Tester and especially on the Rockwell Superficial Tester, according to the proposed method. The impressions which showed a "sinking" type of indentation were very difficult to classify. Just before one reaches the part of the metal which sinks in, a small ridge exists and this causes confusion in classifying. This ridge is readily discernible if you take a real soft piece of brass of approximate hardness Rockwell B10. This has what is referred to as a "sinking" type of indentation but by rubbing the surface with emery paper, after the test is made, it can be shown that there was also a ridge just beyond the "sinking" section. This ridge is also observed by examining the indentation with a small hand magnifying glass.

Another disadvantage of the proposed method is that conversion charts are often desired by engineers, designers, inspectors, etc., who do not have a sample of the material available. They would know, however, the type of material with which they were working, but would not know whether it was "sinking" or "ridging" type.

Reference is made in Mr. Heyer's paper to the difference between the A.S.T.M. test procedure and the procedure given in the Wilson Mechanical Instrument Co. Instruction Book, concerning the time of load application.

Actually the two wordings have the same meaning unless there is flow in the material under test. Under such conditions no Rockwell test can be recorded unless a time factor is specified. The Rockwell test is a static test and is of the proper value when the forces reach equilibrium. Now, if there is material which flows thus causing creep of the needle, then it is necessary that the supplier and user get together and determine a time factor agreeable to both or, if such a time factor is written into general specifications, it should be determined by someone who has made an accurate study of the various time factors for different materials at different hardnesses. In actual practice, most materials can be tested on the Rockwell Tester where the pointer comes to rest much before 15 seconds, the time interval established by the author, whereas on the other hand, some materials such as zinc may require a much longer time for the needle to come to rest.

---

[1] Assistant to the President, Wilson Mechanical Instrument Co., Inc., New York, N. Y.

Mr. F. M. Howell.[2]—Mr. Heyer is certainly to be congratulated upon his further work on this subject of hardness relationships, and I am glad to see that he has carried it down to a Brinell of 50 and hope he will extend it down to even lower hardnesses.

Comparison of a large number of carefully conducted tests involving many alloys and tempers of aluminum with the curve that Mr. Heyer shows for the relationship between Rockwell B and Brinell hardness with the 500 kg load, shows that when these tests are carried out in strict accordance with the A.S.T.M. procedure, almost all the results fall within the limits defined by his two extreme curves, that is, the line for the sinking type and the line for the ridging type.

This is true except at the upper range of hardness. Our results showed a greater divergence in the Brinell range from about 130 up to about 180, a greater spread than he has shown, and also it appears from his points that maybe he should have shown a little greater spread because some of those points in that neighborhood are outside the lines.

In connection with the relationship between hardness and tensile strength, it is interesting to note that, in the case of certain aluminum alloys at least, extended aging at elevated temperatures causes the hardness to continue to increase after the point has been reached where the tensile strength starts to decrease.

I have not examined the type of indentation obtained in our tests to see whether they are of the ridging or sinking type, but I would expect them to be more or less intermediate and of the so-called flat type.

One other thing I want to point out is that unless these tests are run in strict accordance with the specifications, we find a much greater divergence from these curves, so I think it is important that the tests be run very carefully. Some of the very hurried tests that are made in production will not give the correlation that can be found from very careful tests.

Mr. S. M. Arnold[3] (*presented in written form*).—This paper calls attention to the fact that some metals are depressed around the indentations on the Brinell, Rockwell, and Vickers hardness tests. On the other hand, some are ridged and some of the metals do not consistently show either a ridge or a sinking type of depression. The author has shown that by plotting the hardness relationships for these various metals against each other they fall in two groups: those which exhibit ridging and those which exhibit sinking. By this method you appear to get better correlation between the various hardness testing methods. It is also to be noted that the Army-Navy, and Wilson Mechanical Instrument Co. curves are at an approximate average position.

We have made Rockwell tests on the following metals to determine whether they can be segregated according to sinking and ridging types of depression. The results are as follows:

	Hardness Rockwell, B Scale	Type of Indentation
8 per cent phosphor bronze..	89.5	Indeterminate
Copper nickel experimental alloy..................	92.5	Ridging
K Monel..................	84.5	Indeterminate
Aluminum alloy 195 HT.....	46	Indeterminate
Nickel silver..................	93	Ridging
Everdur..................	95	Indeterminate
Copper..................	52	Ridging
Aluminum alloy 523.........	21.5	Ridging
Brass grade A..................	88	Ridging
Brass grade B..................	87	Ridging
Beryllium copper............	97	Flat
Cold rolled steel............	81.5	Ridging
Magnesium alloy J_1H........	36.5	Indeterminate

---

[2] Chief, Mechanical Testing Div., Aluminum Research Labs., Aluminum Company of America, New Kensington, Pa.

[3] Bell Telephone Laboratories, Inc., New York, N. Y.

It will be noted that of the 13 metals tested, 5 are marked "indeterminate." Three observers checked with a binocular microscope and where they were unable to agree as to the character of the depression, the character has been marked "indeterminate." Inasmuch as 5 of the 13 metals, or approximately 35 per cent, are in the indeterminate class, we feel at the present time that this proposal of separating the metals as to the character of the depression, after indentation test, as being one of interest chiefly in the laboratory and of less significance for testing in the plant. As the data indicate that the Wilson Mechanical Instrument Co.'s chart and the Army and Navy conversion curves in general fall about midway, we feel such curves have most to recommend them for practical hardness conversion work, eliminating as they do the necessity on the part of the operator of characterizing the depression.

It is clear that this difference in behavior of metals under the indentation test is significant, but if there is a question as to the type of indentation much of its value in the shop is lost. For the present, as time permits, complete conversion tables for each specific metal should be prepared in a manner similar to that already completed for cartridge brass.

MR. REID L. KENYON.[4]—As chairman of the committee to which Mr. Heyer referred, I should like to say that the committee was endeavoring to find some means of giving help to the many people who are requesting that something be done about hardness conversion. A conversion relationship for cartridge brass was developed without much difficulty. The conversions for steel were worked out in the higher hardness ranges and have been published, but, as has been said, in the lower hardness ranges, there is such a wide spread in work-hardening characteristics that no single conversion takes in all materials.

There were two alternatives that the committee considered. One was that which Mr. Lysaght favored, of compiling sufficient data to have a correlation or a conversion curve for each different material. That would require considerable time, although obviously it would be the best solution. In the meantime, it was thought, some less accurate but nevertheless useful relationship might be worked out along the line that Mr. Heyer's paper has described.

The committee hoped there would be a number of people who might be able to examine impressions on samples that they had tested in their own laboratories and check the results that are included in Mr. Heyer's paper. The committee welcomes the presentation of the data that has been already made, but there really needs to be much more checking done.

MR. ROBERT H. HEYER[5] (*author's closure by letter*).—Mr. Howell points out that his Rockwell B-Brinell data for aluminum alloys generally fall within the limits of the curves of Fig. 3 except for a greater spread in the high hardness range. In all cases the curves for "sinking" and "ridging" materials were not intended as limiting lines but as average lines for these classes of materials.

One of the two precipitation hardened aluminum alloys tested had a "flat" and the other a "ridging" contour. It would be interesting to know whether Mr. Howell's alloys having hardnesses up to 180 Brinell have "ridging" contours. We have not made enough observations of precipitation hardened alloys to know whether they develop the ridging contours which are characteristic of cold-worked materials.

---

[4] Associate Director of Research, The American Rolling Mill Co., Middletown, Ohio.

[5] Supervisor, Metallurgical Laboratory, The American Rolling Mill Co., Middletown, Ohio.

It is apparent from the discussions by Messrs. Lysaght and Arnold that the method of classifying indentation contours was not clearly described in the paper. Mr. Lysaght is correct in his observation that "sinking" type indentations have an elevated or ridged zone outside the depressed zone at the edge of the indentation. According to the author's method of classification, the contour at the edge of the identation—the intersection of the sphere and the plane—is the criterion of "ridging" or "sinking." Ridging impressions have sharp edges and sinking impressions have rounded edges as observed naturally or with a low magnification glass. Impressions whose edges are not readily classified as rounded or sharp are put in the intermediate or "flat" category.

The use of the term "ridging" was apparently misleading since nearly all indentations have a measurable elevation from the original plane surface, but only in the case of cold-worked metals, and possibly some hardened by other means, does the elevation take the form of a sharp ridge at the very edge of the indentation.

Mr. Lysaght refers to the case where the test sample is not available for visual classification but the engineer or inspector knows the type of material. If the material is known to be in the soft annealed state or in a hard-rolled or hard-drawn temper, it can safely be assumed that it will have "sinking" (rounded) or "ridging" (sharp) types of indentations, respectively. In these instances use of the special conversions based on identation contours should give more reliable results than conventional conversion charts. For example, if the material has a hardness of 45 on the R30T scale and is known to be in a hard-rolled state, its Rockwell B hardness is probably about 25 instead of 45 as given by the Wilson Chart No. 38.

In discussing the time of load application in Rockwell testing, Mr. Lysaght states that for materials which flow under the test load, ". . . no Rockwell test can be recorded unless a time factor is specified. The Rockwell test is a static test and is of the proper value when the forces reach equilibrium."

According to A.S.T.M. Standard E 18 – 42, Section 7 (g): "The time of application of the major load shall be established and accurately adhered to when comparing results. As a general rule, an interval of full application of the major load of not more than 1 sec. is best. For soft metals the penetration will 'creep,' causing variations as high as ten hardness numbers. With such metals the operating lever should be brought back the moment it is seen that the major load is fully applied."

Evidently the issue is whether or not the Rockwell test is based on equilibrium. The procedure recommended by The Wilson Mechanical Instrument Co. and confirmed in Mr. Lysaght's discussion is not in accord with A.S.T.M. Standard E 18 – 42.

Mr. Arnold states that the Army-Navy and Wilson Mechanical Instrument Co. curves are at an approximate average position between the author's curves for "ridging" and "sinking" type materials. In Fig. 1 the Wilson curve has been drawn only for the RB *versus* R30T data. It will be found, however, that in all the relationships represented in Fig. 1 the Wilson curve follows the "sinking" curve for the lower hardnesses and the "ridging" curve for the higher hardnesses. Only in a small range of hardness does it approximate an average value.

The author and his associates, like Mr. Arnold and his associates, examined identations which could not be classified definitely as "ridging" or "sinking." When these samples were assigned to the intermediate or "flat" classification, it was found that their various hardness values conformed nicely to intermediate positions in the charts. It should, therefore, be emphasized that the principal purpose of these charts, in their present state of development, is to reduce the large conversion errors which are often made when conventional single line conversion relationships are used. For this purpose it is necessary to observe whether the indentations are clearly of the "sinking" (rounded edge) or "ridging" (sharp edge) type, or to know whether the material is in the soft annealed (rounded edge) or hard-worked (sharp edge) state.

As Messrs. Arnold, Lysaght, and Kenyon have pointed out, the ultimate goal should be specialized conversion relationships for each different material.

ROUND-TABLE DISCUSSION ON ORGANIZING THE CLASSIFICATION OF INDUSTRIAL WATERS

INTRODUCTION[1]

By W. C. Schroeder[2]

That the whole subject of industrial water chemistry still partakes of the mystery of alchemy to the minds of many engineers is evident from the current approach of otherwise well-trained engineers to the problem. About a year ago the author attended a meeting in which the application of organic chemicals in boiler water treatment was being considered. The engineers involved were fully convinced that potato peelings or similar waste could be thrown into the water to produce any and all effects produced by quebracho, cutch, or other carefully prepared treatments. They had no idea that water treatment for boilers could be precisely prescribed and accurately controlled.

This incident might be dismissed with the simple statement that the individuals were ill-informed, except that able executives and engineers of some of the large industrial organizations follow similar reasoning. This is evidenced by the installation in some fairly large boilers of devices and equipment which have no chance of being successful in preventing scale, corrosion, or other operating difficulties.

It is a distinct responsibility of the water chemist to remove, in so far as possible, the mystery surrounding water treatment and to tell his story in simple, standardized language. Through A.S.T.M. Committee D-19 on Water for Industrial Uses, methods have been developed for standards or tentative standards for sampling and analyzing industrial waters and for reporting the results. A basis has thus been established for determining and recording the characteristics of water in common terms. Obviously standards for the interpretation of these characteristics in terms of usability and performance would be a most desirable next step. This Round Table Discussion will show one way in which classification may be achieved.

In the work on classification of Subcommittee V of Committee D-19 a broad-scale educational program on water treatment is not planned, although there is obviously a need for it. The work of this subcommittee is intended, rather, to develop a method of classification that will impart real meaning to reported water analysis and form a basis for judging how an unfamiliar water can be used in a given industrial application.

The members of the committee are fully aware that the problem is not one to be approached lightly. In fact, this whole general discussion is a trial balloon to determine how well even this preliminary attempt at classification will be received. It is hoped that discussion from the floor will show whether the difficulties can be surmounted. A suitable method of classification would be as useful as the water analysis itself.

---

[1] Published by permission of the Director, U. S. Bureau of Mines, Washington, D. C.

[2] Assistant Chief, Fuels and Explosives Service, U. S. Bureau of Mines.

METHODS OF CLASSIFYING WATERS

Some methods of classifying waters are much older than methods of water analysis. Doubtless the distinction between fresh and salt water was made long before the advent of even rudimentary chemical methods. Again, and at a much later time, fresh waters were broken down into hard and soft water, largely on the basis of the way they behaved with soap. At this point, the development of methods of classifying water for general use seemed to stop, in contrast to the steady improvement and refinement of methods for its chemical analysis. As a more thorough knowledge of the nature of the water was built up, there arose a corresponding awe of the many and complex factors that entered into the effects it created.

As a matter of fact, however, the development of methods for classifying water did not stop, but branched off and became highly specialized, each industry developing a body of ideas applicable to its own water problems. Within each field, specialists arose whose experience enabled them to judge from the chemical analysis whether the water was suitable or could readily be made suitable for a given industrial use. The development of their ideas, improvements in methods of treatment, and the growth of knowledge in particular branches of water treatment are the subject of many papers in the literature. This material is of great value, but it is frequently scattered, and a bare beginning has been made toward assembling it into a useful form for those who are not specialists.

Some of the earliest attempts at classification were made in connection with the work of the Geological Survey on water supplies. In 1908, a formula for classification was devised by Stabler[3] which was used extensively by the Survey. In 1911, Palmer[4] suggested a classification for natural waters based on the percentage of total cation and anion groups in the water. From this was derived a character formula for the water. In 1923, Collins[5] further developed the use of graphic presentation of water analysis based on charts or diagrams in which the various constituents were indicated by different colors and their quantity in equivalents per million by the length of the bars representing them. This idea permitted a simple and effective comparison of natural water analysis by inspection of the charts.

Other proposals have been made more recently that permit calculation of the quantity of softening chemicals needed for lime-soda softeners.[6] This might be considered as a method of classification in so far as a particular scheme of water treatment is concerned. The early method suggested by Palmer[4] also forms the basis for a later development for classifying irrigation waters.[7] In this case the water is not only broken down into certain cation and anion groups but is further subdivided on the basis of specific concentrations of certain ions. Langelier and Ludwig[8] have added materially to the earlier ideas of classification by simplifying the terminology and developing more accurate methods of plotting. The procedures that they propose are aimed particularly at obtaining a character formula for a water based on its carbonate hardness and alkalinity.

---

[3] Herman Stabler, "The Industrial Application of Water Analysis," *Engineering News*, Vol. 60, p. 355 (1908). See also U. S. Geological Survey Water Supply, *Paper no. 274* (1911).

[4] Chase Palmer, "The Geochemical Interpretation of Water Analysis," Geological Survey, *Bulletin 479* (1911).

[5] W. D. Collins, "Graphic Representation of Water Analysis," *Ind. Eng. Chem.*, Vol. 15, p. 394 (1923). See also W. D. Collins, "Natural Waters Available for Industrial Use," *Chemical and Engineering News*, Vol. 21, p. 1062 (1943).

[6] J. W. Arbatsky, "Graphical Calculation of Softening Conditions of Water," *Gas- und Wasserfach*, 83; 90, 116 (1940).

[7] R. A. Hill, "Salts in Irrigation Water," *Proceedings*, Am. Soc. Civil Engrs., Vol. 67, p. 975 (1941).

[8] W. F. Langelier and H. F. Ludwig, "Graphical Methods for Indicating the Mineral Character of Natural Waters," *Journal*, American Water Works Assn., Vol. 34, p. 335 (1942).

It is not the purpose of the papers in this Round-Table Discussion to consider in detail these earlier methods of classification, for in general they were developed to cover much more limited fields than the one now in view. At the same time, they often demand extensive calculation and methods of plotting which are useful primarily to specialists in water treatment. In undertaking this work, the Subcommittee on Classification, of Committee D-19, hopes to develop a method which can be readily understood by most engineers, which is applicable to all industrial uses of water, and which will help water specialists to record and classify their experience. It is anticipated that the method developed upon this basis probably may be less definite than most of those already suggested, but that its simplicity and general applicability will make it much more useful.

CLASSIFICATION BY COMPARING CHEMICAL ANALYSIS

For industrial purposes, the composition of natural water represented by the formula H_2O may be considered the same under all conditions. In the strictest chemical sense, water can consist of molecules made up from 1 to 6 units of H_2O, and it can contain various isotopes of hydrogen or oxygen, but these differences are normally unimportant. The impurities in the water alone determine the suitability of a given natural water for an industrial process. The classification of the water then depends on the character and amount of impurities that it contains. These will vary from less than 0.003 per cent, by weight, dissolved solids for some natural water up to 3.5 per cent for ocean water. Very few natural waters contain more dissolved solids than ocean water, although industrial solutions frequently contain much higher concentrations.

Both the character and the amount of impurities are measured by chemical analysis. An over-all measure of the amount can be obtained by evaporation and driving off the water as steam and simply weighing the deposit of solid that remains. If the water was clear at the start, the result should furnish a rough measure of the amount of impurities. However, this value by itself does not distinguish between impurities and, hence, tells little. Individual constituents can be determined by chemical procedures that isolate and measure each one. Although most waters contain a large number of such constituents, for most industrial purposes it is only necessary to be concerned with a few, and in many instances only three or four. Detailed methods already reported by Committee D-19 are available for these analyses.

Owing to the nature of the chemical methods that are used, the substances that are determined are generally ions and not salts or chemical compounds. For instance, in a water that contains sodium chloride (NaCl or common salt) there would be two determinations, one for sodium and one for chloride. Where more impurities are present in the water, it may be necessary to determine 8 or 10 individual ions. From the results it is impossible to tell how these ions were linked or whether they were linked at all when they were present in the water. It is furthermore undesirable to attempt to make such hypothetical combinations for a complex solution. The same water, evaporated at two different boiler pressures, may deposit salts that are quite different. To avoid the misrepresentation inherent in hypothetical combinations, it is usually desirable for the chemist to report the material which he actually determines in the ionic form.[9]

Ions such as calcium (Ca), magnesium (Mg), sodium (Na), iron (Fe), carbonate (CO_3), hydroxide (OH), phosphate (PO_4), sulfate (SO_4), and chloride (Cl) are often very important in water analysis. The authors of the several papers in this discussion will point out how these ions behave in the industrial processes under consideration and, if the effect is detrimental, what methods of water treatment may be used to overcome it.

Results of chemical analysis for gases in water are not reported in ionic form. The analysis usually represents gases dissolved in the water, and they are so reported. Oxygen, carbon dioxide, hydrogen sulfide, chlorine, and hydrogen are types of gases that may exert marked effects in industrial processes. The reputation that dissolved oxygen has earned as a promoter of destructive types of corrosion is so well deserved and so universally known that it forms the background for much of the thinking on corrosion problems in atmospheres of water vapor, or in water. Results for dissolved gases are not reported in the analyses of water samples which are used as a basis of classification in the papers in this Discussion. The gas content of natural waters is not fixed, but depends on the temperature, pressure, and other conditions of the sample at the moment. As a result, the gas analysis is generally significant only when it measures the volume and character of the gas as it actually exists in the water during the process.

Chemical tests are sometimes made for other constituents, such as organic matter, silica, and oily matter. Their composition is frequently unknown, and, in other cases, interpretation of their determination is uncertain. Methods of reporting these analyses are therefore arbitrary, but for comparative purposes they have value.

These procedures for determining and reporting the impurities in water form a basis for the development of methods of classification. It is not believed that classification by formulas or graphs could as yet be developed for application to the wide variety of uses for water in industrial processes. Such methods would usually be more difficult to understand and to use than the original analytical data of the sample.

Most specialists in water treatment judge the suitability of a water for a given industrial process by comparing its analysis with the analysis of other waters whose behavior in the process is known. Broad experience makes it possible to do this accurately to predict the suitability of the unknown water. This process is extremely flexible, and yet it can serve as a means for greatly increasing the usefulness of water analysis even to the layman.

On this basis, the problem of classification resolves itself into writing down, in a simple and systematic form, the experience and knowledge that have been accumulated on treating water for various industrial purposes. As a first step, nine waters have been selected as a cross-section of the natural waters normally encountered in this country. The water-treatment specialists who have prepared the papers for this Round Table discussion will describe as concisely as possible the way each of these nine samples would be expected to act in certain applications. So far as possible, they will indicate the basic chemistry that guides their thinking and emphasize the ions or constituents that have the most important effect in the industrial processes under consideration. The nature of the treatment that may improve these waters for a given use will also be pointed out.

---

[9] Standard Method of Reporting Results of Analysis of Industrial Waters (D 596 - 41), 1942 Book of A.S.T.M. Standards, Part III, p. 814.

A water identified solely by its chemical analysis may then be classified by comparing its mineral content with the analysis of the nine standard samples.[10] It can be assigned a number indicating that its properties are relatively close to those of one of the standards, or it may indicated as falling between two of the samples. The classification must take into account the process in which the water is used, for certain constituents will have different weight in different processes. The same water can thus fall into different classes depending on its use. This does not seem to be an important defect in the scheme, for identification of the intended field of use must always be considered as the first step in classification.

Application of the method of classification throughout this discussion is confined to the use and treatment of natural waters for industrial processes. No attempt has been made to extend the method to special waters, such as the concentrated brines that are used in some processes.

The first paper in the symposium, by W. D. Collins, is concerned with the selection of the water samples that are the basis for classification. He shows why these samples were selected and suggest others that it may be desirable to include in the group. He also discusses other constituents of the water, not shown in the table of analysis, which are important.

The second paper, by L. B. Miller, is concerned with water used in paper manufacture. Since this field is too large to be covered adequately in a single relatively short paper, his discussion is confined primarily to the use of water in the single phase of paper manufacture. He indicates how and why certain constituents of the water have a marked effect on the process. This is the groundwork for pointing out the effect of the individual samples.

The third paper, by J. A. Holmes, discusses the use of the waters represented by these nine samples as feedwater for boilers operating between 100 and 400 psi. He discusses when and why certain constituents form scale and others sludge, those substances that tend to cause corrosion, and what can be done about it. The paper succinctly presents the story of each of the waters as feedwater for low-pressure boilers (up to 400 psi.) and summarizes the effect of various methods of water treatment.

The final paper, by R. E. Hall, relates to the use of the waters represented by these samples as feedwater for boilers operating above 400 psi. As the pressure increases, feedwater requirements become more stringent, particularly above 800 psi. Evaporated make-up is used for practically all boilers operating above 1000 psi., and even evaporated water is given some treatment for boiler use. Mr. Hall outlines the special problems that would be encountered for each of the nine waters in the operation of high-pressure boilers.

The four papers in this Round Table Discussion are, of course, only the beginning of application of this method of classification to industrial waters. If this initial work indicates that the method offers a useful tool for expressing the meaning of a water analysis in language understandable to layman and specialist alike, it will be extended to cover other industrial uses of water. The members of the committee are asking for your discussion and advice, first, on the method which is being tried; second, on the water samples so far selected as a basis of classification; and, third, on the application of the method in the industries discussed in the individual papers.

---

[10] Committee D-19 has also considered a method of classification which is not based on the chemical analysis but instead on tests to determine the actual behavior of the water. Where well developed tests are available, this method can be useful, but its scope is still relatively limited. In many cases, however, tests to determine the behavior of the water are of great assistance in interpreting the water analysis.

[See General Discussion, p. 1082.—Ed.]

TYPICAL WATER ANALYSES FOR CLASSIFICATION WITH REFERENCE TO INDUSTRIAL USE[1]

By W. D. Collins[2]

For the purposes of the discussion that is to follow, water analyses given in Table I were selected as typical of waters that are encountered in the operation of industrial establishments in the United States.

Analyses Nos. 1, 3, 5, 6, and 7 make up a table of typical analyses that is distributed by the U. S. Geological Survey in correspondence relating to the composition of natural waters. Together they represent roughly the composition of public water supplies used by about 45 per cent of the total population of the cities in the United States that have more than 20,000 inhabitants.

To the five Geological Survey typical analyses it seemed desirable to add No. 2 of Table I to represent a highly colored water of low mineral content such as is found in swampy areas, especially in the southeastern coastal area. Analysis No. 4 was added to represent water with hardness intermediate between the water of the Great Lakes (No. 3) and the hard ground waters represented by No. 5. Analysis No. 8 was added to represent the waters much harder than No. 6 that are used for some public and private supplies. Analysis No. 9, ocean water, was added because it is used largely for condensers on ships and by some plants located by the ocean.

Table I was prepared early in the formulation of the program for this Round Table Discussion. Table II gives some analyses that have been suggested as additions to Table I or possibly as substitutes for some of the analyses in Table I.

Analysis A in Table II is submitted as a typical water of low mineral content that carries in solution an excessive amount of iron. Water of this character is found in many wells in the Atlantic Coastal Plain. Some of these wells supply water that is less hard than the water represented by analysis A. Except for the iron, these waters are similar to No. 1 in Table I in their content of dissolved mineral matter.

A review of the individual analyses of which No. 4 in Table I is the average suggests that the silica reported is too high. The analyses represent a river water that usually carries a large amount of suspended matter. Much of the time a considerable proportion of the suspended matter is very fine and difficult to filter out. It seems likely that some of the individual analyses include silica from suspended matter that was not removed by filtration. Analysis B in Table II is probably more representative of the most widely used waters with hardness intermediate between the hardness of Nos. 3 and 5.

There is a class of waters that carries in solution more silica than is reported in Analysis No. 4 of Table I. Analyses C and D in Table II are representative of the waters that carry in solution between

---

[1] Published by permission of the Director, U. S. Geological Survey.

[2] U. S. Geological Survey, Washington, D. C.

40 and 50 ppm. of silica. Most of these waters of high-silica content are sodium bicarbonate waters.

The analyses in Tables I and II, except for No. 2 in Table I, show only the ordinary dissolved solids. They do not include dissolved gases and other properties that may have more effect than the dissolved solids on the industrial value of a water. The content of gases may be variable for water from a given source. Waters almost identical in general chemical character may have very different amounts of dissolved gases, color, or suspended matter. Therefore it has seemed necessary to discuss these characteristics separately instead of trying to include them in individual analyses.

TABLE I.—TYPICAL ANALYSES OF SURFACE AND GROUND WATERS.

	Analysis No. 1	Analysis No. 2	Analysis No. 3	Analysis No. 4	Analysis No. 5	Analysis No. 6	Analysis No. 7	Analysis No. 8	Analysis No. 9
PARTS PER MILLION									
Silica (SiO_2)	2.4	6.0	12.0	37.0	10.0	9.4	22.0	14.0	...
Iron (Fe)	0.14	0.01	0.02	0.73	0.09	0.2	0.08	1.8	...
Calcium (Ca)	5.8	5.2	36.0	62.0	92.0	96.0	3.0	155.0	420
Magnesium (Mg)	1.4	1.7	8.1	18.0	34.0	27.0	2.4	46.0	1 300
Sodium (Na)	1.7	5.7	6.5	44	8.2	183.0	215.0	78.0	10 710
Potassium (K)	0.7	1.4	1.2		1.4	18.0	9.8	2.6	390
Bicarbonate (HCO_3)	14.0	13.0	119.0	202.0	339.0	334.0	549.0	210.0	150
Sulfate (SO_4)	9.7	2.3	22.0	135.0	84.0	121.0	11.0	389.0	2 690
Chloride (Cl)	2.0	10.0	13.0	13.0	9.6	280.0	22.0	117.0	19 350
Nitrate (NO_3)	0.54	...	0.1	2.2	13.0	0.2	0.52	3.4	...
Bromide (Br)	...	...	...	...	...	...	...	...	70
Dissolved solids	31.0	66.0	165.0	426.0	434.0	983.0	564.0	948.0	35 000
Color	...	200.0	...	...	...	...	...	...	...
Total hardness as $CaCO_3$	20.0	20.0	123.0	229.0	369.0	351.0	17.0	576	...
EQUIVALENTS PER MILLION									
Calcium (Ca)	0.29	0.26	1.80	3.09	4.59	4.79	0.15	7.74	...
Magnesium (Mg)	0.12	0.14	0.67	1.48	2.80	2.22	0.20	3.78	...
Sodium (Na)	0.07	0.25	0.28	1.91	0.36	7.96	9.35	3.39	...
Potassium (K)	0.02	0.03	0.03		0.04	0.46	0.25	0.07	...
Total cations	0.50	0.68	2.78	6.48	7.79	15.43	9.95	14.98	...
Bicarbonate (HCO_3)	0.23	0.21	1.95	3.31	5.56	5.47	9.00	3.44	...
Sulfate (SO_4)	0.20	0.05	0.46	2.81	1.75	2.52	0.23	8.10	...
Chloride (Cl)	0.06	0.28	0.37	0.37	0.27	7.90	0.62	3.30	...
Nitrate (NO_3)	0.01	0.00	0.00	0.04	0.21	0.00	0.01	0.05	...
Total anions	0.50	0.54	2.78	6.53	7.79	15.89	9.86	14.89	...

Analysis No. 1—Catskill, supply of New York City.
Analysis No. 2—Black Creek, Middleburg, Fla. (Swamp water containing organic material).
Analysis No. 3—Niagara River, filtered for public supply of Niagara Falls, N. Y
Analysis No. 4—Untreated Missouri River water—average.
Analysis No. 5—Wells 30 to 60 ft. deep used for public supply of Dayton, Ohio.
Analysis No. 6—Well 2,090 ft. deep used for public supply of Maywood, Ill.
Analysis No. 7—Well 330 ft. deep at Smithfield, Va.
Analysis No. 8—Wells 250 to 400 ft. deep, Roswell, N. Mex.
Analysis No. 9—Ocean water—average.

Hydrogen-Ion Concentration (pH).—The hydrogen-ion concentration measured by the pH value is probably, next to hardness, the characteristic of a water supply in which there is the most interest. Waters that could be represented by almost any of the analyses in the table might have a pH from 5 to 8. In general, however, the lower pH is associated with the waters of low mineral content like No. 1, No. 2, and A. The sodium bicarbonate waters like C and D are likely to have a pH around 8 or even higher.

Carbon Dioxide.—The free carbon dioxide in a water is usually the largest factor in determining the pH. Any of the waters shown may have either low or high content of free carbon dioxide. In general the waters low in dissolved mineral matter like No. 1, No. 2, and A have proportionally higher content of free carbon dioxide than the harder waters. The sodium bicarbonate waters, C and D, often contain no free carbon dioxide.

Hydrogen Sulfide.—Almost any water may carry in solution appreciable amounts of hydrogen sulfide. The presence of this gas may be the most important chemical characteristic of a water from the industrial viewpoint. Many waters high in hydrogen sulfide are exceedingly corrosive.

TABLE II.—ANALYSES OF WELL WATERS.

	Analysis A	Analysis B	Analysis C	Analysis D
Date of collection	4/25/32	5/4/38	8/25/43	8/25/43
PARTS PER MILLION—EXCEPT pH				
Silica (SiO_2)	18	15	47	42
Iron (Fe)	26	0.25	0.03	0.03
Calcium (Ca)	9.9	63	1.2	4.0
Magnesium (Mg)	4.2	20	0.4	0.8
Sodium (Na)	2.3	7.2	121	268
Potassium (K)	2.6	1.8		
Bicarbonate (HCO_3)	44	227	297	656[a]
Sulfate (SO_4)	11	54	1.0	1.0
Chloride (Cl)	2.0	3.8	14	36
Fluoride (F)	...	...	1.2	2.2
Nitrate (NO_3)	0	1.8	0	0
Total dissolved solids	107	277	335	680
Total hardness as $CaCO_3$	42	240	4.5	14
pH	...	...	7.5	7.9
EQUIVALENTS PER MILLION				
Calcium (Ca)	0.49	3.14	0.06	0.20
Magnesium (Mg)	0.35	1.64	0.03	0.07
Sodium (Na)	0.10	0.31	5.25	11.64
Potassium (K)	0.07	0.05		
Total cations	1.01	5.14	5.34	11.91
Bicarbonate (HCO_3)	0.72	3.72	4.87	10.75
Sulfate (SO_4)	0.23	1.12	0.02	0.02
Chloride (Cl)	0.06	0.11	0.39	1.02
Fluoride (F)	...	...	0.06	0.12
Nitrate (NO_3)	0	0.03	0	0
Total anions	1.01	4.98	5.34	11.91

[a] Includes equivalent of 6.9 ppm. of CO_2.

Analysis G—Well No. 1. Water Department, Annapolis, Md.

Analysis B—Well 105 ft. deep, part of municipal supply, Mansfield, O.

Analysis C—Well No. 5, Alexandria, La. 996 ft. deep, 12 in. diameter.

Analysis D—Well No. 6, Alexandria, La. 448 ft. deep, 12 in. diameter.

Oxygen.—The oxygen content of water may be anything from zero to saturation, or beyond. Its amount may be a large factor in the value of a water and in the cost of its treatment. There is no necessary relation between the oxygen content and the content of solid mineral constituents.

Color.—Although Analysis No. 2 of Table I was included because of the high color, it is possible to have waters of almost any composition with almost any amount of color. In general, however, the highly colored natural waters are low in mineral content. There are hard waters in southern Florida that are highly colored. In Mississippi and other States in the Central Plain there are sodium bicarbonate waters like C and D in Table II that are highly colored. In other parts of the country are well waters that have picked up considerable color from lignite and other carbonaceous material in the formations from which the waters are obtained.

TABLE III.—APPROXIMATE NUMBER OF CONSUMERS IN LARGE CITIES SERVED WITH WATER OF THE GENERAL CHARACTER SHOWN BY TYPICAL ANALYSES IN TABLES I AND II.

Analysis	Hardness, ppm.	Dissolved Solids, ppm.	Consumers	
			Thousands	Per cent
No. 1	20	31	11 484	37.68
No. 2	20	66		
A	42	107	31	0.10
No. 3	123	165	13 075	42.91
No. 4	229	426	2 206	7.24
B	240	277	1 172	3.85
No. 5	369	434	1 731	5.68
No. 6	351	983	266	0.87
No. 8	576	948	270	0.89
No. 7	17	564	16	0.05
C	4.5	335	216	0.71
D	14	680	5	0.02
			30 472	100.00

Suspended Sediment.—The tables of typical analyses give no results for suspended matter, although this may be the determining factor in the evaluation of a source of water supply. The amount of suspended matter in well waters is normally vanishingly small. The amount in a surface water may be from nearly zero up to almost 1 per cent by weight for many streams and up to 10 or 15 per cent at times in very muddy streams.

In an effort to make a rough estimate of the relative use of the different types of water, excepting ocean water, the waters used for the public supplies of about 56,700,000 consumers were checked against the analyses in Tables I and II, mainly on the basis of hardness and dissolved solids. The results shown in Table III account for about 53 per cent of the consumers in the larger cities of the United States. Omitted from Table III are fairly large groups served with water having hardness from 50 to 60 ppm., from 90 to 110, and from 150 to 160. For practical purposes these groups could probably be included with one or another of the groups represented by the typical analyses shown in Tables I and II. For the consideration of industrial value and treatment requirements some of the typical analyses might be combined, as will appear in other papers of this Round Table Discussion.

[See General Discussion, p. 1082.—Ed.]

THE USE OF SELECTED WATERS IN PULP AND PAPER MANUFACTURE

By Lewis B. Miller[1]

The purpose of this paper is to discuss the use of certain natural waters as process waters in the manufacture of pulp and paper products. These selected waters have been chosen by Committee D-19 as representative of natural waters of the United States which are used for industrial purposes.

The analyses of the selected 10 waters are limited to certain inorganic constituents. These are pertinent to the use of these waters as process waters for the manufacture of pulp and paper; in some cases these constituents are very important and determine the types of paper or pulp which may be manufactured through their use. Certain other characteristics of the water, in addition to those inorganic constituents which are presented, are of greater or less importance in determining the suitability of a given water source for the manufacture of pulp and paper products. Some of those properties which are of major importance, particularly in the manufacture of high-grade pulp and paper products, are the following:

1. *Color.*—Color in water may be due to natural organic materials such as are present in swamp water, to colored industrial wastes such as dyes, etc., or to wastes such as emanate from the manufacture of certain explosives. Most of these materials, if present in appreciable amounts, will affect the brightness and color of bleached pulp or paper products. In general, in the manufacture of high-grade pulp and paper products, waters which contain color in excess of 5, expressed in platinum units, are considered undesirable for such use.

2. *Organic Plant Growths.*—The presence of such materials as sticks, bark, and leaves interfere in the manufacture of the higher grades of pulp and paper, and steps are ordinarily taken to remove such substances before the water is used in the manufacturing process. Growths of aquatic plants in natural waters above or near the intake of manufacturing plants frequently interfere with operation by breaking off and floating into the intake where they may become entangled in the pumping machinery or become shredded in such equipment and pass on to the process water. Heavy growths of algae may be undesirable for somewhat similar reasons.

3. *Industrial Wastes.*—Industrial wastes discharged to a natural water supply above the intake of a pulp or paper plant are frequently undesirable. Such wastes may be of an almost infinite variety, their effects upon the manufacturing operations may be equally diverse, water treatment required to neutralize their effects is greatly varied, so that the presence of such wastes in a process water supply forms an individual problem. Secondary effects also arise from the presence of such wastes as may serve as a food supply for prolific growths of bacteria which may give rise to the development of slime in subsequent paper manufacturing operations.

---

[1] Chemical Engineer, Consulting Div., W. H. & L. D. Betz, Philadelphia, Pa., Chairman, Water Committee, Technical Association of the Pulp and Paper Industry.

4. *Water Temperature.*—Water temperature is of significance in the manufacture of paper products in that it affects machine operation and certain chemical reactions which occur in the paper making operation.

5. *Turbidity.*—Inorganic or organic constituents suspended in water in the form of turbidity affect the color and brightness of fine papers. The specific nature of the suspended materials undoubtedly determines to some extent the degree of turbidity permissible in the manufacture of any specific grade of fine paper; thus culm from the anthracite coal regions would probably be more deleterious than a light-colored silica or clay in process water. In general, 10 ppm. of turbidity is considered the upper limit of turbidity for process water. Many cases will occur where a lower limit for turbidity should be specified.

6. *Inorganic Constituents in Addition to Those Cited in the Analyses.*—At least two other inorganic constituents of the water used in pulp and paper are of considerable significance; these are the manganese content of the water and its hydrogen ion concentration or pH value. Manganese is a more or less common constituent of process waters and, of course, every water possesses a pH value. Other inorganic constituents such as sulfides, heavy metals, etc., which are not commonly found in appreciable quantities in raw waters, may be of considerable importance in special cases in paper manufacture where these substances are present in appreciable quantities.

These brief remarks will serve to indicate that certain constituents and properties of the water supply, in addition to those constituents chosen for describing the properties of the ten selected waters in Mr. Collins' paper, are of importance and sometimes of major importance in the manufacture of pulp and paper.

Water Quality Required for Manufacture of Pulp and Paper Products:

Considering the water quality requirements for the pulp and paper industry as a whole is almost comparable to considering water quality requirements for all types of industry, since the quality of water required for the manufacture of different grades of pulp and paper varies in the most extreme manner. Thus, in the processing of certain low-grade pulps, or perhaps these should be more correctly designated as wood fibrous products, and of low-grade papers such as asphalt roofing felts, quality requirements for process water are comparatively low. At the other extreme, is the quality requirement for process water used in the manufacture of certain facial, cigarette, filter, photo-sensitive papers and electrical and condenser tissues, where water of a very high quality is required. These preliminary remarks will indicate that to discuss the applicability of the ten chosen waters to the manufacture of all types of pulp and paper would require that the numerous grades of paper now on the market be first divided into certain arbitrary groups, depending upon the quality of water required for their manufacture, and that the applicability of the several selected waters be then discussed in relation to paper manufacture for each of these groups. A similar service would then be required for the numerous varieties of pulp. This would be a task of hopeless length and one which we believe no individual at the present time is prepared to do. By limiting the discussion to the quality of water required for the manufacture of a definite group of paper products, it should be possible to discuss the applicability of the ten selected waters to such use to some purpose.

Water Quality Requirements for the Manufacture of Fine Papers:

In this connection the Water Committee of the Technical Association of the Pulp and Paper Industry[2] has been investigating for the past four years the quality of water required for the manufacture of certain high-grade or fine papers such as bond, ledger, book, and writing papers. These investigations have been carried out by direct discussions with the operators of mills manufacturing these papers and through the medium of several questionnaires sent to such paper mills. A large amount of exact information on the quality of water required for the manufacture of these papers is, therefore, available. The present discussion will, therefore, be limited to a consideration of the applicability of the ten selected waters to the manufacture of such high-grade papers. To further clarify the discussion, it should be remarked that the quality of water required for the manufacture of high-grade papers such as bond, ledger, book, and writing papers is not as exacting as that required for the manufacture of filter, photo-sensitive, electrical and condenser papers, etc., but the quality requirement is considerably higher than for most types of papers.

Discussion of the Selected Waters:

The analyses of the ten selected surface and ground waters are presented in Table I taken from Mr. Collins' paper.[3] In addition, the pH of saturation (pHs) as calculated by the Langelier formula, is given for each of the selected waters.

For reasons of clarity and conciseness, the writer has chosen to discuss the effects of each constituent of water upon the manufacture of high-grade papers, and to apply the principles thus presented to the cases of the individual waters, rather than to discuss at length the effects of each constituent in the case of each water.

TABLE I.—TYPICAL ANALYSES OF SURFACE AND GROUND WATERS.

	Water No. 1	Water No. 2	Water No. 3	Water No. 4	Water No. 5	Water No. 6	Water No. 7	Water No. 8	Water No. 9	Water No. 10
Silica as SiO_2	2.4	6.0	12.0	37.0	10.0	9.4	22.0	14.0	...	17.5
Iron as Fe	0.14	0.01	0.02	0.73	0.09	0.2	0.08	1.8	...	27.1
Calcium as Ca	5.8	5.2	36.0	62.0	92.0	96	3.0	155.0	420.0	10.6
Magnesium as Mg	1.4	1.7	8.1	18.0	34.0	27	2.4	46.0	1 300	5.0
Sodium as Na	1.7	5.7	6.5	44	8.2	183	215.0	78.0	10 710	...
Potassium as K	0.7	1.4	1.2		1.4	18	9.8	2.6	390	...
Bicarbonate as HCO_3	14.0	13.0	119.0	202	339	334	549.0	210.0	150	37
Sulfate as SO_4	9.7	2.3	22.0	135	84	121	11.0	389.0	2 690	43
Chloride as Cl	2.0	10.0	13.0	13	9.6	280	22.0	117.0	19 350	Trace
Nitrate as NO_3	0.54	...	0.1	2.2	13.0	0.2	0.52	3.4	...	...
Bromide as Br	...	...	...	...	...	...	...	...	70	...
Total dissolved solids	31	66	165	426	434	983	564.0	948.0	35 000	126
Color	...	200	...	...	...	...	...	...	...	...
Total hardness as $CaCO_3$	20	20	123	229	369	351.0	17.0	576	...	...
pH	...	...	...	...	...	...	...	...	...	6.65
pH of saturation at 60 F	9.4	9.5	8.0	7.7	7.3	7.3	8.4	7.3	...	9.0

All values expressed in parts per million except pH and color.

Effect of Silica:

In general, soluble silica in the quantities encountered in process waters is of minor importance in the manufacture of high-grade papers. It is well known that soluble silica, if present in sufficient concentrations, will impart a quality designated as "tinniness" to papers, which in most cases is considered undesirable. It seems doubtful that the concentrations of soluble silica encountered in the several selected waters would have any great effect upon this property of the paper. (It may be added parenthetically that soluble silica in quantities such as are encountered in some of the waters under discussion has been found to have a definitely deleterious effect when such waters are used for washing certain types of pulp. Under these conditions and with the water used, the silica appears to coagulate and adsorb on the pulp and cannot be washed out. An undesirable increase in the ash content of the pulp occurs.)

---

[2] The Water Committee of the Technical Association of the Pulp and Paper Industry has the following membership:

L. B. Miller, Chairman
C. M. Connor, Glassine Paper Co.
Miss L. E. McGrath, Booth Chemical Co.
R. B. Martin, Wallace and Tiernan Co.
W. F. Mitchell, Pennsylvania Salt Mfg. Co.
J. G. Patrick, West Virginia Pulp and Paper Co.
E. N. Poor, American Cyanamid & Chemical Co.

The Water Committee has also received extensive assistance in the course of these investigations from R. G. Macdonald, Secretary of the Technical Association of the Pulp and Paper Industry, Richard Bingham, Assistant to the Secretary, and Vincent F. Waters, formerly Assistant to the Secretary, and now Editor, Southern Pulp and Paper Journal.

[3] W. D. Collins, "Typical Water Analyses for Classification with Reference to Industrial Use," see p. 1057.

Chloride Content:

In the manufacture of the high-grade papers indicated, the chloride content of the paper is ordinarily of little significance, except as it affects the total dissolved solids content of the water. This statement is intended to refer to the effect of the chloride upon the quality of paper itself. High chloride content of water does have a marked effect upon paper manufacture because of its corrosive effect and because of the accelerating effect which it has upon electrolytic corrosion of the metal parts of the paper machine. This is particularly marked and particularly undesirable in the case of cylinder mold and Fourdrinier wires upon which formation of the paper sheets takes place. These corrosive effects are observed in pitting, de-zincification, and fatigue cracking of the Fourdrinier wires. In a secondary way, this destruction of the wire may have its effect upon the quality of paper through lack of uniformity, imperfections, etc., of the paper due to imperfections in the wire resulting from corrosion.

Sea water as exemplified in water sample No. 9 and brackish waters are undesirable for the manufacture of papers of any quality because of their corrosive effect, and this applies equally to high-quality papers. Waters such as Nos. 6 and 8 may contain sufficient chlorides to have a slight effect in this way, but the effect would not be marked.

It may be remarked in passing that in the manufacture of electrical insulating paper even a few parts per million of chloride in a process water may be very undesirable because of the effect upon the electrical properties of the resultant paper.

Iron Content:

From the standpoint of the manufacture of fine papers, iron is one of the worst offending substances present in process water. Even in very small amounts its presence causes staining of the resultant paper and a decrease in brightness. It is generally considered that for the manufacture of high-grade papers, process water should not contain iron in excess of 0.1 ppm. expressed as Fe. Quantities of iron much in excess of that indicated cannot be tolerated.

In addition to affecting the quality of paper directly due to its presence in the process water, this substance always presents a danger through the possible growth of crenothrix (iron bacteria) with all of its attendant undesirable features.

Although the waters under consideration were not analyzed for manganese content, this element is being included with iron and discussed at this point because the effects of manganese upon paper manufacture are very similar to those of iron. If anything, it is a worse offender than iron and it is generally considered that manganese present in process water in excess of 0.05 ppm. is undesirable.

Effect of Color:

In an earlier paragraph of this paper, some reference was made to color and its undesirable effects. In the waters under consideration only water No. 2, which is a swamp water, has been investigated for color. For the manufacture of high-grade paper it is generally considered that the water should not contain more than 5 units of color. Obviously, water No. 2 does not lend itself without treatment to use as process water in the manufacture of this type of paper.

Nitrate:

We have no information indicating that the presence of nitrate in the concentrations noted in the several waters under discussion has an undesirable effect upon the manufacture of high-grade papers.

Bromine:

We have no information indicating that bromine in the form of bromide in process water is in itself undesirable. Normally, however, bromine is not present except in sea water or brines which are undesirable because of their high salt content.

Sodium and Potassium:

We have no data to indicate that the presence of sodium and potassium is particularly undesirable in the manufacture of high-grade papers, except that their presence in quantity indicates the presence of a high total salt content in the water. The effect of high alkali chloride content in accelerating corrosion of metal parts of the paper machine and particularly of the costly wire upon which the paper is formed has been previously discussed.

The presence of potassium or sodium salts, especially the chlorides of these metals, is very undesirable in the manufacture of electrically resistant papers.

Total Dissolved Solids:

When considering the effect of total dissolved solids, much depends upon the nature of the dissolved solids in question. In general, it is considered that process water for the manufacture of fine papers should not contain in excess of 200 ppm. of dissolved solids, even when these dissolved solids are of the less objectionable type. Under this condition, only waters Nos. 1, 2, 3, and 10 would be considered as satisfactory from the standpoint of total dissolved solids content.

Sulfate Content:

In general, sulfate content of process waters is of lesser significance except as the sulfate content is an index of dissolved solids content. Since calcium sulfate scale is not formed until calcium sulfate is present in concentrations considerably in excess of 1000 ppm., the specification as regards total dissolved solids automatically limits the content of sulfate far below a concentration at which a calcium sulfate scale may form. Sulfate may therefore be considered to be of minor importance in process water.

Calcium, Magnesium, and Total Hardness Content:

Since the calcium, magnesium, and total hardness content are closely interrelated in their effects on fine paper manufacture, these substances will be discussed together. It is well known that many types of sizing, such as rosin size, react with soluble calcium and magnesium compounds to form slightly soluble rosin soaps. These rosin soaps are slightly soluble, sticky products which do not result in an appropriate sizing effect upon paper such as is obtained by the products resulting from the reaction of these rosin sizes with alum. The result is that the rosin which reacts with the hardness in the water is lost and larger quantities of the sizes are required in order to obtain the desired sizing effects upon the papers. Thus, increase in size usage occurs, resulting in an increased manufacturing cost, and frequently in a non-uniform sizing effect on the paper itself. In this connection, total hardness is of importance since both magnesium and calcium compounds behave similarly in this respect.

In the terminology of the water chemist, hardness is considered to be of two types: carbonate hardness and non-carbonate hardness. If the calcium or magnesium present in the water is combined with the carbonate radical to form either soluble carbonates or bicarbonates, the hardness is considered to be of the carbonate variety. If the calcium and magnesium are present as soluble compounds other than carbonate or bicarbonate, they are considered to be hardness of the non-carbonate variety.

The non-carbonate type of hardness is undesirable, primarily because of its effect upon sizing, as indicated above. If the hardness present is of the carbonate variety, it may have undesirable effects upon paper manufacture in addition to the effect upon sizing. The carbonates and bicarbonates of magnesium are comparatively soluble. On the other hand, the bicarbonate of calcium is fairly soluble, whereas the normal carbonate is highly insoluble. Consequently, with calcium bicarbonate present, if an increase in the pH of the water occurs due to the addition of an alkaline chemical or through loss of soluble carbon dioxide from the water due to an increase in temperature or an aeration effect, slightly soluble calcium carbonate forms,—frequently in the form of scale. One of the points at which it is very easy to lose carbon dioxide from the water is at the point where the paper sheet is formed; that is, where the stock goes upon the wire, because of the large area exposed to the atmosphere at this point. Slightly soluble calcium carbonate formed at this point tends to form a scale upon and to plug the openings in the wire. This reduces the ease of formation of the sheet and eventually requires that the wire be cleaned. This normally requires a shut-down of the paper machine and treatment of the wire with dilute acid.

In addition to the undesirable effects noted above, the presence of the bicarbonate radical in the form of carbonate hardness or of sodium carbonate or bicarbonate may have a further undesirable effect through the release of carbon dioxide. This may occur through the addition of acidic substances, such as alum, to the paper stock, with the result that the carbonates are converted to free carbon dioxide. Some of the free carbon dioxide may escape from the stock at any time after the addition of the acidic material, but it is most apt to escape where the stock is exposed to the atmosphere to the greatest extent and this is at the point of formation of the paper sheet. The escape of carbon dioxide gas at this point may result in pinholes and blisters in the finished paper sheet.

For the manufacture of fine papers, it is generally considered that the total hardness should be limited to a maximum of 100 ppm. expressed as $CaCO_3$ and that the bicarbonate, or as it is commonly expressed, the alkalinity to methyl orange, should be limited to 45 ppm., both expressed in terms of HCO_3. Under these circumstances and from the standpoint of hardness and bicarbonate content, only waters Nos. 1, 2, and 10 would be considered satisfactory.

Stability of the Water:

From the standpoint of their use as process water, one of the important properties has not been determined on these waters, with the exception of water No. 10. We are referring to the pH value. For the purposes of the present discussion, however, we are assuming that the pH of these several waters did not vary more than 0.5 pH from neutrality. With this consideration in mind, we have calculated the pH of saturation (pHs) for the water at 60 F. by the Langelier method. These values are presented in the last line of the table. The pH of saturation for a specific water is that pH at which stability exists for a given temperature. Above the pH of saturation, scale formation may occur, whereas below that pH value corrosion may occur. The further the pH of saturation departs from the true pH of the water, as determined by experiment, the greater will be the tendency toward scale formation or corrosion, other things being equal. Assuming that the pH of each water is somewhere near neutrality, this would indicate that waters Nos. 1, 2, and 10 are quite corrosive, waters Nos. 3 and 7 somewhat so, while the remaining waters are substantially in equilibrium. (No attempt has been made to compute the pH of saturation of water No. 9, which is sea water.) This calculation is of some importance, since it indicates to the operator in a general way the tendency of the process water in question to cause corrosion or to form scale.

Summary and Conclusion:

In summarization, a brief statement will be made regarding the applicability of each of the individual waters to the manufacture of papers of high quality, the reason for their rejection where they are found unsatisfactory, and an indication of what treatment may be used to render them satisfactory for use in the manufacture of fine papers.

Water No. 1.—This water is an excellent water for the manufacture of fine papers with the exception of the fact that the iron content is slightly above the preferred maximum specification for this constituent. For some types of high-grade papers, however, this water may be quite satisfactory. If necessary, the iron content may be further reduced by a suitable method of treatment such as by passing the water through an appropriate type of zeolite.

Water No. 2.—This water is entirely suitable for paper manufacture, except for its high color content. The color can be satisfactorily reduced by flocculation of the water under carefully controlled conditions.

Water No. 3.—This water is satisfactory as a process water for the manufacture of fine papers although it is somewhat above the values in hardness and in bicarbonate content, which are preferred in waters for this use. If found necessary, it could be reduced in hardness and in bicarbonate content somewhat by the addition of lime. If, on the other hand, it was found that bicarbonate was causing difficulty in operation rather than hardness, the bicarbonate could be reduced and converted to sulfate by treatment of the water with sulfuric acid, followed by aeration to drive off the carbon dioxide.

Water No. 4.—This water is undesirable for use in the manufacture of fine papers for several reasons: It is somewhat on the high side in silica content, although this is one of the points of lesser importance. It is much too high in iron content, in hardness, and bicarbonate content, and in total solids content. There is probably no economical method of treatment to make this water suitable for the use desired, but it could be greatly improved by cold lime-soda treatment which would suitably reduce the iron and appreciably reduce the bicarbonate and hardness content. Total dissolved solids would be too high following such treatment, and total solids could not be reduced within desirable limits except by a very costly method of treatment.

Water No. 5.—This water is too high in bicarbonate and in total hardness content. It is also high in total dissolved solids. The same remarks apply to this water regarding the reduction of these particular constituents as were made in connection with water No. 4.

Water No. 6.—This water is too high in iron content, in hardness, in bicarbonate, and in total dissolved solids content. The same remarks apply to this water as were made regarding water No. 4. This water is also rather high in chloride content.

Water No. 7.—This water is high in sodium bicarbonate content and in total solids. No economical form of treatment would overcome this feature of the water, but its qualities could be considerably improved by acid treatment followed by aeration to reduce the bicarbonate content.

Water No. 8.—This water is too high in iron, hardness, soda, bicarbonate, sulfate, and chloride content, and in total dissolved solids. No system of treatment that would prove economical could be applied to render this water suitable for process use in the manufacture of fine papers.

Water No. 9.—Water No. 9 is sea water and is not suitable for use in the manufacture of fine papers.

Water No. 10.—This water contains 27.1 ppm. of iron and would be totally unsuited to the manufacture of fine papers from this standpoint. In other respects it would be satisfactory. Suitable treatment as by aeration and filtration would render the water satisfactory for use as process water.

In conclusion, it has been the objective in this paper to indicate the quality of water required for the manufacture of certain types of high-grade papers and the waters under consideration have been discussed from this standpoint. This particular group of fine papers has been chosen as a means for discussing the applicability of the ten selected types of water as process water for the manufacture of these papers since they have been studied intensively from this standpoint for the past four years by the Water Committee of the Technical Association of the Pulp and Paper Industry, and a great deal of information is available on this subject. It has been pointed out that a few high-grade papers require an even higher quality water for process water than those discussed here. Many lower grade papers have far less rigid requirements for process water. Paper pulps also have greatly varied water requirements from the quality standpoint, the same as with paper manufacture. That is, high-grade pulps require comparatively pure waters, whereas low-grade pulps are far less rigid in their requirements. Because of the great variety of pulp and paper products, no attempt has been made to discuss the applicability of the several waters in question to the entire field of pulp and paper manufacture.

REFERENCES

(1) T.A.P.P.I. Tentative Standard E 600 s-44, "Chemical Composition of Process Water for Fine Paper Manufacture," *Paper Trade Journal*, May 25, 1944.

(2) T.A.P.P.I. Special Report No. 298, "Survey of Paper Mill Water Requirements." Report prepared by T.A.P.P.I. Water Committee and published as a confidential report by the Technical Association of the Pulp and Paper Industry.

(3) Lewis, B. Miller, "T.A.P.P.I. Survey of Paper Mill Water Requirements," *T.A.P.P.I. Tech. Assn. Papers*, Series 23, p. 433 (1940). This is a brief resume of Special Report No. 298.

(4) T.A.P.P.I. Special Report No. 333, "Process Water Used for Fine Paper Manufacture." Report prepared by T.A.P.P.I. Water Committee and published as a confidential report by the Technical Association of the Pulp and Paper Industry.

(5) Lewis, B. Miller, "Process Water Used for Fine Paper Manufacture." *Paper Trade Journal*, December 30, 1943. This is a brief resume of Special Report No. 333.

[See General Discussion, p. 1082.—ED.]

TREATMENT OF VARIOUS TYPES OF WATERS FOR OPERATING PRESSURES ABOVE 400 PSI.

By R. E. Hall[1]

As the title indicates, this discussion of industrial waters is limited to the use thereof for steam-generating purposes. As its main feature, the discussion must emphasize any special treatment needs engendered by higher operating pressures. In so doing, however, it must answer a number of pertinent questions: Is 400 psi., or in general operating pressure, a logical basis on which to make distinctions of treatment? Are not such distinctions better based on rate of heat input to the evaporative surfaces than on a few pounds per square inch of operating pressure one way or the other? Or, on the ratio of the density of liquid and vapor, a figure indicative of the driving force of steam bubbles in promoting circulation?

Also, are there other factors than those given in the tables presented by Mr. Collins which if included in the analytical data on waters will be guideposts on the type, or, for that matter, merely the need, of treatment? In classifying or interpreting water analyses consideration must be given particularly to the small users and the small power plants, since large users and large power plants will have their experts on water to guide them. Any approximations or simplifications however must apply in all cases.

Is it feasible to agree on a few general criteria for boiler waters and steam, and on the basis thereof reach conclusions concerning interpretation of any water analysis in question?

In attempting to answer these questions, we shall start with principles applicable to all operating pressures, dealing thereafter with more specific conditions.

Principles Applying to Treatment for All Operating Pressures

In addition to deaeration, which is mechanical, two distinct considerations are involved in any treatment of waters to be used in generation of steam.

1. *Limitation of Impurities in Steam:*

Steam of all pressures terminates similarly with condensation to water. Hence in all cases, impurities in the original water must be manipulated in such a manner as to prevent their imparting detrimental, for example, deposit-forming or corrosive qualities to the steam. Organic contamination which promotes carryover of boiler water in the steam, ammonia, carbon dioxide, and silica are the principal offenders. Exceptions to this general principle are those cases in which the steam condenses without contact with metal conduits which guide the flow of condensate, for example, by being exhausted to atmosphere. But in all cases in which effort is made to save the condensate, or in steam heating, whether the condensate is saved or not, these principles apply.

---

[1] Director, Hall Laboratories, Inc., Pittsburgh, Pa.

2. *Character of the Boiler Water:*

In the boiler water we must provide for two drastically different sets of conditions as follows:

(*a*) Those characterizing the dilute over-all boiler water, whose concentration of dissolved and suspended components may be controlled as desired by blowdown. The alkalinity relationship and the concentration of treating chemicals to be maintained therein, also the various types of pretreatment best suited and commercially available for the raw waters to be used, have been widely discussed in the engineering journals and power magazines, so that we can well omit further discussion here. As a part of its work in interpreting waters or arriving at some classification of them, we believe this committee cooperating with the Joint Research Committee on Boiler Feedwater Studies, might well agree upon some maximum concentration of total solids to be maintained in the boiler water; perhaps 2500 ppm. or even 3500 ppm. for pressures below 400 psi., and perhaps 1500 ppm. for pressures above 400 psi. We emphasize, however, that in any such recommendations, the question again becomes paramount, whether rating, or rate of heat absorption, is not a better criterion of the dividing line than operating pressure.

(*b*) Those conditions obtaining as the over-all boiler water or films thereof evaporate and concentrate at steam-water interfaces such as those of the boiler evaporative surfaces, and of any boiler water carried mechanically by the steam into the superheater. The concentration of dissolved solids therein attained at equilibrium has no dependence on blowdown, but, instead, is a function of temperature increment at the interface, boiler pressure, and the behavior of the dissolved solids in relation thereto. Very definitely, the extent to which these conditions obtain is more influenced by rating or by circulation than by pressure. We shall consider these conditions later in this discussion.

Let us assume now that satisfactory treatment can be attained by using well-established commercial processes, and turn our attention to the question: What relationships can be derived from analytical data on waters such as presented by Mr. Collins that will be guideposts on type of treatment, or need for treatment?

Available Carbon Dioxide:

Let us consider the question of the bicarbonate radical first. It might be well to list as one item of the analysis, the carbon dioxide available in the bicarbonate and carbonate radicals found in the water, since in boiler use, some, and at times much of this may find its way into the steam to contaminate it. In the analyses of Mr. Collins' Table I,[2] the available carbon dioxide thus derived varies from a minimum of 9.4 ppm. for No. 2 water, to a maximum of 396 for No. 7 water. Dependent upon the temperature at which the feedwater heater operates, and also on its venting, some decomposition of the bicarbonate radical will occur with loss of carbon dioxide, presumably to the extent of 30 to 50 per cent. If the final equilibrium in the boiler water is maintained by treatment with phosphate, practically all of the carbon dioxide carried into the boilers, except that small portion lost in blowdown, will be evolved into the steam. If there is no treatment of the boiler water, some proportion of the available carbon dioxide will be precipitated as calcium carbonate. If the boiler water is maintained alkaline by use of sodium carbonate, considerable carbon dioxide will be provided in the steam by decomposition thereof.

---

[2] W. D. Collins, "Typical Water Analyses for Classification with Reference to Industrial Use," see p. 1057.

Suppose this committee, in agreement with the Boiler Feedwater Studies Committee, were to stipulate a maximum limit to carbon dioxide in the steam, for example, a maximum of 15 ppm., which corresponds approximately to its concentration in steam made from lime-soda treated water. It then becomes possible to estimate roughly whether or not the water requires external treatment, and the permissible types of treatment. Thus, assuming 50 per cent loss of the available carbon dioxide through the vent of the heater, we may establish the following relationship:

$$\frac{\text{Available } CO_2 \text{ ppm.} \times 0.5 \times \text{Percentage of Make-up Water}}{100} \leqq 15$$

If the value found is equal to or less than 15 (Nos. 1 and 2, Table I, for maximum make-up) external treatment may be omitted, unless the value of total hardness as $CaCO_3$ considerably exceeds that of the HCO_3 radical (both best expressed as e.p.m.); or in other words, unless permanent hardness largely predominates. In that case, dependent on the amount of the permanent hardness, treatment for hardness removal by any of the standard commercial methods may be advisable. (We note that in Mr. Collins' tables, no example is given of a water low in bicarbonate but high in permanent hardness, a condition found in the Ohio River at Wheeling, the Schuykill River at Philadelphia, and the Monongahela River at Pittsburgh.) If the value found is greater than 15 (Nos. 3, 4, 5, 6, 8, Table I; A, B, Table II, for maximum make-up) and the value of total hardness as $CaCO_3$ is comparable to or greater than that of HCO_3, it becomes advisable to treat the water by a process which simultaneously effects removal of hardness, and, elimination of available CO_2 to the extent required for its proper limitation in the steam. Only in the case of high value for HCO_3 and low for total hardness as $CaCO_3$ (No. 7, Table I; C and D, Table II) is simple elimination of CO_2 by acid treatment alone advisable.

In a great number of cases, of course, the maximum of 15 ppm. of CO_2 in the steam will be considered too high, a minimum of as little as possible frequently being the objective. These cases will represent mostly larger operations, however, usually with personnel skilled in interpreting waters.

Approximation of Blowdown:

If, as noted above, a general criterion is established for permissible total solids in the boiler water, the items in the analyses of dissolved solids and total hardness as calcium carbonate provide simple means of approximating blowdown required. We shall assume clear feedwater. If the natural water is one in which suspended matter to any extent is usually present, it should be filtered. If the water is subject to occasional periods of turbidity, then, as required, the blowdown can be adjusted to take cognizance of the turbid condition, or, filtration can be provided, justified by the severity of the occasional turbidity. Properly, we believe, the analyses as presented by Mr. Collins, do not include an item of suspended solids. The function of the analyses is to record the fundamental characteristics of a water; transient variations therefrom can scarcely be considered in a typical analysis. However, the analysis might record that the water in question is subject to seasonal or aperiodic variation of turbidity, or both, as the case may be.

Such variations must, of course, be known, and allowance therefor be made in uses of the water for specific purposes. A good example of aperiodic variation is given by Elliott in his study of the Delaware River during full flow and during periods of drought, when salt water invades the river from the bay. (*Oil and Gas Journal*, Vol. 42, No. 39, February 3, 1944, pp. 103–108.)

If no treatment of a water is contemplated, then blowdown in per cent, calculated on the basis of feedwater, may be approximated as follows:

Below 400 psi.: Blowdown = (Dissolved Solids ppm./3500) × Per Cent Make-up.
Above 400 psi.: Blowdown = (Dissolved Solids ppm./1500) × Per Cent Make-up.

If treatment in the boiler is contemplated, the approximate percentage of blowdown on the basis of feedwater becomes:

Below 400 psi.: Blowdown = [(Dissolved Solids ppm. + Hardness as Calcium Carbonate ppm.)/3500] × Per Cent Make-up.
Above 400 psi.: Blowdown = [(Dissolved Solids ppm. + Hardness as Calcium Carbonate ppm.)/1500] × Per Cent Make-up.

In case of external treatment, no general considerations on blowdown are possible until after a decision has been reached regarding type of treatment to be used, in accordance with the requirements of limiting carbon dioxide in the steam, as discussed above under the heading "Available Carbon Dioxide."

Sludge Content of the Boiler Water:

How much sludge can be tolerated in the total solids of the boiler water? Quite frequently a limit is given thereto in terms of percentage of the total solids. With such a limit established, and with amount of blowdown known, it becomes a simple matter to calculate approximately the sludge that would be present in the boiler water from the figure of hardness as calcium carbonate in the analysis. Thus:

Sludge (in Boiler Water) ppm. = Hardness as Calcium Carbonate × Per Cent Make-up/Per Cent Blowdown (on Feedwater).

Color and Carryover:

One other factor of the analysis becomes of value in calculations of this type. When concentrated in the boiler water, the natural organic contamination of a water as measured by color is usually decidedly contributory to contamination of the steam by carryover. The waters of the Androscoggin and Wisconsin Rivers are good examples. An approximate measure of this effect for the conditions of any one case is given by

Color (in Units Reported) × Per Cent Make-up/Per Cent Blowdown (on Feedwater).

If the value thus obtained exceeds some standard value agreed upon, the advisability of treatment for removal of the contamination is thus clearly indicated. Where evaporators are used, and their brine is treated, consideration of this factor becomes important in the avoidance of carryover and the concurrent addition of impurities to the evaporated make-up.

These few examples show that by the adoption of a few criteria for the over-all boiler water, analyses of water can be readily interpreted in relation to their use as feedwater. It seems well nigh impossible to establish any general rules for the myriad specific cases, of which the following is an interesting example.

The analysis of the water concerned is as follows:

	ppm.	epm.
Carbonate (CO_3)	32	1.07
Bicarbonate (HCO_3)	250	4.09
Chloride (Cl)	282	7.94
Sulfate (SO_4)	189	3.95
Silica (SiO_2)	24	0.80
Iron (Fe)	trace	
Calcium (Ca)	19	0.95
Magnesium (Mg)	6.6	0.54
Sodium (Na)	357	15.56
Dissolved Solids	1033	
Hardness as $CaCO_3$	74.5	1.49
Available CO_2	203.5	9.25

On the basis of available carbon dioxide, it lies between No. 8 and No. 5 of Mr. Collins' Table I but resembles No. 7 more closely, however, because of its relatively low hardness, and consequent high content of sodium bicarbonate. On the basis of hardness, it lies about midway between No. 2 and No. 3. On the basis of chloride and sulfate, it more nearly resembles No. 6. It is higher in total solids than any water listed in the tables. The supply of water is limited. Sufficiently effective carbon-dioxide removal can be accomplished by lime-acid treatment, or by sodium-hydrogen-zeolite. Treatment by lime-acid will result in considerably higher total solids than treatment by sodium-hydrogen-zeolite, the former, therefore, necessitating higher blowdown value. On the other hand, backwashing and rinsing of the zeolite requires considerable water. In this case, decision was reached that it was better to accept the higher blowdown required by the lime-sulfuric acid treatment, than to obtain the lower blowdown of the sodium-hydrogen-zeolite at the expense of the water necessary for backwashing and rinsing. Besides, if necessary in spite of high blowdown, reduction of silica can be effected as part of the regular procedure.

In general, analogues of waters available for use in specific plants are rather readily found in the well-chosen examples of waters presented by Mr. Collins. The characteristic type of any water as thus determined readily suggests the best-suited procedure in its treatment. At times, of course, as in the above instance, the final choice of treatment is necessarily made on the basis of extraneous circumstances. But as this work on classification or interpretation becomes recognized, and the correct procedure of treatment may thus be judged, at least the number of arbitrary decisions regarding treatment may be held to a minimum with resultant better protection of boilers, and improvement of steam quality.

PRINCIPLES OF TREATMENT MORE SPECIFICALLY APPLYING TO HIGHER OPERATING PRESSURES

In general, as operating pressures are higher, the trend is toward more complete removal of all impurities in the water to be treated, as by evaporators, or by anion-cation exchangers. This applies especially where condensate is available in considerable percentage, as in the utilities. In this way, impurities in the boiler water, other than chemicals added as treatment, are limited in origin to evaporator carryover and condenser leakage plus incidental foreign material which drifts into the system as it operates, but which can be held to low values with care. In industry, however, this trend, while apparent is not so prevalent, particularly through the pressure range of about 900 psi., or higher in some instances.

The typical characteristics of the dilute over-all boiler water for pressures above 400 psi. are not markedly different from those recognized as satisfactory for pressures below 400 psi. Where the boiler water is kept very pure by the use of evaporated make-up, and by holding condenser leakage to a minimum, lower alkalinities, frequently composed entirely of captive alkalinity, are permissible, but if the percentage of treated make-up is considerable, and total solids in the boiler water and separation of sludge are greater, alkalinities much in line with those held for pressures below 400 psi. are advisable. Usually, the total solids in the boiler water, and the percentage of sludge therein, are maintained lower the higher the operating pressure.

Even with these things done, troubles develop. Scales containing silica or analcite or acmite develop, particularly under any layers of sludge that may form in tubes where evaporative rate is high. Iron-oxide sludges accumulate in the boilers, and tubes become pitted or channeled through loss of metal by combination with the bonded oxygen of the boiler water. These troubles develop as films of the over-all boiler water evaporate and concentrate at steam-water interfaces. This occurs independently of the concentration of dissolved solids in the main body of the boiler water, and is dependent upon temperature increment at the interface, upon boiler pressure, and upon the physical-chemical characteristics and the relative proportions of the dissolved solids in the boiler water. Such conditions develop more commonly in boilers of higher pressure, and there are reasons for this which will be advanced shortly. They may be caused as well in boilers of lower pressure where the heat input rates are exceptionally high. For instance, a boiler which has operated very satisfactorily using coal for fuel may, if gas is substituted for coal, begin losing tubes by the development of analcite scale on the generating tube surfaces. Under these circumstances, the tube surfaces on the furnace side, devoid of slag, especially those of the first row of generating tubes, absorb far more heat, and the higher rate of evaporation results in the scale formation.

As explained in our paper "A New Approach to the Problem of Conditioning Water for Steam Generation," *Transactions*, Am. Soc. Mechanical Engrs., July, 1944, pp. 457–474, results such as these are due to increment of temperature Δt, of the evaporative surfaces, whereupon, the film of boiler water in contact evaporates to a concentration that represents equilibrium with the operating pressure of the boiler at the increased temperature imposed upon it, thus developing what we have termed a concentrating-film boiler water, with the surprising characteristics which have been described in the above paper.

Why are these effects more pronounced in boilers of higher operating pressures? To answer the question, let us consider some of the factors associated with the generation of a cubic foot of steam, at 400 psi., and at pressure intervals of 800 psi.

SOME FACTORS MET IN GENERATING 1 CU. FT. OF STEAM

Temperature Increase:

The temperature of the saturated steam generated at these intervals of pressure is as follows:

Pressure, psi.	Temperature Saturated Steam, deg. Fahr.	Temperature Increase, deg. Fahr.	
		0 to 400 psi.	400 to 2800 psi.
0	212	236	238
400	448		
1200	569		
2000	637		
2800	686		

The temperature increase with change in operating pressure from 0 to 400 psi. is 236 F.; from 400 to 2800 psi., 238 F. Over this temperature range, the solubilities of the boiler-water salts undergo change. Some, like sodium chloride and sodium hydroxide, increase in solubility; others, like sodium sulfate, sodium phosphate, and sodium silicate, decrease in solubility. But increase in temperature in the over-all boiler water in itself is not enough to account for the development on the one hand of hide-out, and on the other, of hard deposits such as sodium silicate, sodium aluminum, and sodium iron silicate, with lesser amounts of sodium sulfate and sodium phosphate.

In the above-mentioned paper, we have considered what happens to a film or thin layer of boiler water which as a steam bubble forms remains in contact with the evaporative surface of the tube. If the temperature of the latter on the water side is raised a few degrees above temperature of the saturated steam, we point out that deposition of sodium salts of inverse solubility curve is readily explained. In such a film, high concentration is developed by substances whose solubilities increase with increasing temperature. Thus, such increase in concentration of caustic soda readily promotes the formation of magnetic iron oxide by combination of the boiler metal in the tube with the bonded oxygen of the boiler water.

Whatever most effectively promotes the development of these effects in steam-water interfaces occurring at evaporative surfaces likewise promotes the problems characteristic in boilers of higher operating pressure, but also met in boilers of lower pressure at points of especially high heat input as in the example cited relative to change from coal to gas fuel.

Density Ratios:

In searching for a reason why higher operating pressures should be particularly effective in developing conditions typical of temperature increment at steam-water interfaces, let us consider the density or number of pounds of saturated steam per cubic foot, and the ratios of the higher pressure densities to that of 400 psi. The values are as follows:

Pressure, psi.	Density, lb. per cu. ft.	Ratio, Density to Density at 400 psi.
400	0.894	1.0
1200	2.83	3.05
2000	5.39	6.03
2800	9.92	11.1

These data show the rapid increase of density with pressure. Thus, if two bubbles of steam of equal size are generated at an evaporative surface, one at 400 and the other at 2000 psi., at the latter pressure the weight of steam in the bubble is 6.03 times that in the bubble generated at 400 psi.

More work has been done to generate the steam bubble at 2000 psi. than that at 400 psi. Is the work actually 6.03 times as much?

Btu. Ratios:

A measure of the work is found in the heat input through the tube to produce the bubble. So, let us next consider the amounts of heat required to develop one cubic foot of saturated steam from water at the same temperature, and the ratios of these amounts to that required at the temperature corresponding to 400 psi. The data are as follows:

Pressure, psi.	Heat Required to Produce 1 cu. ft. of Saturated Steam from Water at the Same Temperature, Btu.	Ratio of Heat Required at Different Pressures to That Required at 400 psi.
400	693.7	1.0
1200	1704.2	2.46
2000	2463.8	3.55
2800	2654.6	3.83

The ratio of the heat required at 2000 psi. to that required at 400 psi. to produce 1 cu. ft. of steam is 3.55. Thus, in the production of steam bubbles of equal size at 2000 psi. and 400 psi., the heat input through the tube must be 3.55 times as much for the former as for the latter. For bubbles of equal volume, therefore, it is natural that troubles originating at the steam-water interface thereof with the film of water on the boiler tube, should be greater the higher the operating pressure. On the one hand, the bubble of higher pressure attains its volume more slowly than the bubble of same volume at 400 psi. if at equal rates of heat input, thus making the life period of any such steam-water interface longer. On the other hand, if the rate of heat input is faster at the higher pressure, greater opportunity exists for development of incremental temperature at the steam-water interface (Δt), increase of which results in higher concentrations in the concentrating-film boiler water, with correspondingly greater chance of scale deposition, or combination of boiler metal with the bonded oxygen of the boiler water.

Liquid - Saturated Vapor Ratios:

There is still another angle to be considered in summing up why the reactions occurring at the steam-water interface are more severe at higher pressures than lower. At the several pressures used in presenting these data, the densities or pounds per cubic foot of liquid and saturated vapor, and their ratios, are as follows:

Pressure, psi.	Density, lb. per cu. ft.		Density Ratio, Liquid to Saturated Vapor
	Liquid	Saturated Vapor	
400	51.5	0.894	57.6
1200	44.1	2.83	15.6
2000	37.6	5.39	7.0
2800	29.9	9.92	3.0

At 400 psi., the density of the liquid water is 51.5, and of the saturated vapor, 0.894, their ratio being 57.6. At 1200 psi., this ratio has diminished to 15.6. These figures signify a great decrease in the driving force of steam bubbles in promoting circulation as between 400 psi. and 1200 psi. This also means less driving force to separate the bubble from the evaporative surface of a tube, and consequently a longer life period of the steam interfaces at the surface. Another point that arises for the same reason of lesser driving force is that freedom of passage to the steam drum without interposition of any deterrent forces is the more necessary as operating pressures increase.

An Illustrative Example:

Let us consider an illustrative example which is furnished by boiler X operating at 1250 psi. It is comprised essentially of water walls, and a boiler-tube section with some 20 sectional headers. The boiler is thus in reality a community of a few more than 20 practically separate "boilers" with the drum serving as the community center, all separate circuits leading therefrom eventually returning thereto.

Early in March, the third row boiler tube of sectional header 11 failed because of scale and corrosion beneath the scale, necessitating replacement of the tube. Sludge and scale underneath characterized a number of the top or first row of boiler tubes across the sectional headers. The same condition existed spottily in the second, third, and fourth rows. Quite evidently, beneath the sludge, conditions of concentrating-film boiler water existed with resultant hard scale formation. The boiler section was thoroughly cleaned.

One month and two days later, tube 11-3 again failed from corrosion by the bonded oxygen of the boiler water. The first row tubes contained sludge beginning about 1 to 3 ft. in from the downtake header, and extending several feet upward in the tubes. Underneath the sludge was the inevitable hard scale. Likewise, under the patches of sludge in the other rows of tubes, hard scale had formed.

Other headers and tubes in the water-wall "boilers" were not inspected because repeated examinations had shown nothing but excellent conditions, and no difficulties had been experienced in them. The records bear out that statement.

Thus, in this assembly of "boilers," operating on identical water, with operating pressure of 1250 psi., and with the drum as the community center, the water-wall members remain clean, the boiler-section members become dirty. Can it be that with identical treatment conditions for all members, these conditions are ineffective in those several "boilers" constituting the boiler section, and particularly in certain ones as section 11, while at the same time being fully effective in those boilers constituting the water walls? Is it not more likely that the identical treatment conditions are equally effective in all of the "boilers," but in some of them the driving force of the steam bubbles in promoting the required circulation must overcome too much resistance to function effectually? In other words, do the water-wall members clean house spiritedly and effectively at the expense of their more sluggish neighbors?

If the answer to the first of those three questions is "yes," this committee should inaugurate an interpretation or classification of boiler waters based on such differences of behavior.

CONCLUSION

Quite obviously, the writer has overstepped the apparent limits of a discussion on interpretation or classification of natural waters. In justification thereof, he believes that any such interpretation or classification of water for the use of generating steam must envisage the diverse conditions met in the span of operating pressures and rates of heat input. Reasonably, as a first step, classification might be subdivided on the basis of uses in which steam is the product, and those in which it is not.

[See General Discussion, p. 1082.—ED.]

CLASSIFICATION OF FEEDWATER FOR BOILERS OPERATING BETWEEN 100–400 PSI.

By J. A. Holmes[1]

Very few natural waters are suitable for boiler feed use without some form of treatment. The science of water treatment is rather involved because no two waters nor any two boiler installations are exactly the same. However, from experience the analyst learns to make certain observations of a water analysis so that the general characteristics and behavior of these waters as boiler feed can be forecast.

It may be stated that any solid or gas in water is or can be undesirable and in some way helps to cause scale, foaming, or corrosion, the compounds of silica, calcium, and magnesium forming sludge (often called mud) or scale, the compounds of sodium and potassium causing foaming or carryover, and the gases causing corrosion. The question as to whether sludge or scale is formed (assuming no boiler feedwater treatment is applied) depends upon:

1. Pressure
2. Rating
3. Amount of calcium or magnesium and bicarbonate or carbonate ions.

The term sludge defines that solid material that is fine and loose either to settle or to circulate with the boiler water, and scale defines that which precipitates or adheres directly onto the boiler metal. Sludge can nearly always be washed out of a boiler, but scale requires mechanical or chemical removal. Under certain conditions sludge may become baked onto the boiler metal and cause scale. Scale may be either soft or hard, depending on composition rate or method of formation.

Considering pressure only, between 100 and 400 psi., the rate and type of scale formation is not as greatly different as would be expected. Variations in rate of steam production at the boiler surfaces have more effect, and, since the rating, especially in certain sections, often increases with the pressure, there will be more evaporation at that point and hence more conversion of the solids in the water to scale or sludge at that location. Consequently, more deposits are expected at a point where there is a high rate of evaporation.

Theoretically, as the soluble bicarbonate ion is converted by heat to the insoluble carbonate ion, calcium or magnesium carbonate is formed and the resultant carbonates should be sludge. However, many boiler scales will show the presence of carbonates due either to direct formation, baking on after formation, or occlusion with other types of solids that act as cementing agents. This is especially true in heaters, feedlines, feed troughs, and economizers where carbon dioxide is driven off but little or no evaporation occurs.

If there are insufficient bicarbonate or carbonate ions, then calcium sulfate scale tends to form which is harder than carbonate scale and also which may act as a binder to help cement on boiler sludge. Calcium sulfate rarely forms except where there is evaporation.

---

[1] Assistant Vice President, National Aluminate Corp., Chicago, Ill.

The siliceous deposits are more complex, and it is less easy to forecast just how they will precipitate from water. The higher the temperature the more apt they are to form scale and thus more siliceous deposits are generally experienced with increase of pressure and where higher temperatures are encountered due to excessive evaporating rates or in starved sections due to insufficient or improper circulation of the boiler water. The ratio of silica to various amounts of calcium, magnesium or alkalinity of the boiler water influences rate of silica scale formation. In general the harder waters (high in calcium and magnesium) have less silica scale trouble because the percentage of silica is so low that it either is occluded or precipitated in the boiler sludge. When magnesium is also present in sufficient quantity, silica is rarely found in any appreciable quantity in boiler scale because magnesia-silica combinations tend to form sludge rather than scale. However, it is not unusual to find magnesia-silica combinations in feedline scale.

In general foaming or even excessive solids in steam without any noticeable foaming is due to the concentration of soluble salts in the boiler water. Most of these are considered present as sodium or potassium salts. Since potassium is usually present in raw water in only small quantities, it is rarely separated from the sodium in analytical procedures. Here again, however, the associated anion affects the amount of total dissolved solids that can be carried in the boiler water before carryover. Chlorides are considered less apt to cause carryover than sulfates, and the carbonates and hydrates are considered the worst. Suspended solids, oil, and organic matter of certain types also influence carryover.

The total dissolved solids are a measure of the amount of material in the water. For each part per million of solids in the water, there is one pound of solids for each million pounds of water entering a boiler. For each part per million of total hardness as $CaCO_3$, there is approximately one pound of sludge or scale-forming material entering a boiler.

Color naturally present in water is usually associated with swamp water, but can also be due to sewage, plant effluent, or process contamination. Such contaminations are to be avoided because of effect on foaming or scale formation.

Mr. Collins' table of typical analyses does not show oxygen or free carbon dioxide These are generally not considered for raw water, but rather for the boiler feed analysis or as the water enters the boiler after passing through heaters designed to remove these gases. However, in cases where heaters are not used, the quantity of those gases should be determined. Usually the higher the oxygen and carbon dioxide content, the more corrosive the water.

The table also does not show suspended solids which are very important in considering the use of any water. The higher the suspended solids the more mud or sludge is created in the boiler and the presence of any appreciable suspended solids in the water supply usually means the need of proper equipment for its removal. Oil is usually present in water due only to contamination after entering a plant but nevertheless it can be present in some surface waters and its presence greatly affects scale or foaming tendencies of the water and also whether such water needs to be pretreated. Even in minute quantities oil should be removed.

With the above in mind the various

waters in Table I of Collins' paper[2] can be discussed. Analyses 1 to 9 are practically in the order of the increasing total dissolved solids and total hardness. Their undesirability as boiler feedwater correspondingly increases, making it more necessary to use some type of treatment.

No. 1 is the best boiler feedwater. At lower ratings and pressures or where return condensate is a major part of the total feed, little or no treatment for scale is needed because of the low total hardness and silica. However, a small amount of treatment may be needed to insure against scale and to prevent corrosion. At higher ratings with greater percentages of make-up and above 250 psi., treatment is nearly always necessary. No foaming difficulties will be encountered with reasonable control of blowdown and boiler operation. Waters of this type can practically always be treated directly in the boiler unless high in suspended solids, when filtration may be needed to prevent excessive accumulation of mud. No difficulty may be expected from feedline scale.

TABLE I.—APPROXIMATE DISSOLVED SOLIDS (ppm.) AFTER TREATMENT.

Treatment	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9
None	31	66	165	426	434	983	564	948	35 000
Internal	35	70	80	250	180	740	565	795	*
Lime-soda	*	*	115	270	200	750	590	800	*
Lime-Na exchanger	*	*	110	280	200	750	*	810	*
Na-exchanger	31	66	164	425	435	980	560	945	*
Na-H exchangers	31	66	85	280	180	730	125	785	*

* Not applicable.

No. 2 is little different from No. 1 except for color. Frequently natural colors due to tannin leached from logs reduce scale and corrosion. However, in too high quantities, foaming may result. The chief disadvantage of this water is that it would discolor the boiler water to a point where it would be difficult to test and to control treatment for scale prevention by these tests. Water of this type is usually treated directly in the boiler without external treatment except to remove suspended solids. No difficulty is to be expected with feedline scale.

No. 3 is typical of the Great Lakes water supplies. Such waters cause considerable sludge and have just enough sulfate and silica to act as binders. Internal treatment will, in general, give good results if properly handled but for high ratings and pressures external treatment is preferred. No. 3 might be considered the dividing point wherein if the total dissolved solids and total hardness are lower, then internal treatment can be used, but, if higher, external treatment becomes more desirable. This water may or may not cause feedline scale depending somewhat on temperature and type of auxiliary equipment.

No. 4 is a water that without treatment would rapidly form boiler scale and sludge because of sulfates and silica present. This water, unless used at low pressures or with low percentages of make-up, should be treated before entering the boilers. Considerable feedline scale would be formed with this water.

No. 5 is different from No. 4 in that it would cause more sludge because of higher carbonates. The silica is low enough to cause no trouble. This water would cause much feedline scale. It should be externally treated.

No. 6 is different from No. 5 in that the chlorides are high and even with external treatment will have a high dissolved solids content to cause carryover. It likewise will cause much feedline scale.

No. 7 has low hardness with high alkalinity and sodium and potassium and is popularly called "alkali water." Some boiler installations may never experience any scale with this type of water, but foaming will result unless percentage of blowdown is high. This type of water is also typical of those that have caused embrittlement. Treatment by acid exchangers is the best means of reducing total dissolved solids.

---

[2] W. D. Collins, "Typical Water Analyses for Classification with Reference to Industrial Use," see p. 1057.

No. 8 is popularly known as "gyp (gypsum) water" and requires external treatment and high percentages of blowdown. It is a difficult water to use as boiler feed—being very scale-forming in the boiler and its auxiliaries.

No. 9 is a typical analysis of sea water and is included to help check for salt water contamination in samples of water from near coastal areas or from deep wells.

Table I shows approximately the effect of the more common methods of treatment on the typical waters to reduce the total dissolved solids and total hardness. The choice of any of these systems for a particular water depends on the presence of suspended solids, heat balance, available space, and general layout of the boiler plant. There are refinements of these methods and also exchangers that take out anions. A combination of cation and anion exchangers will remove all solids except silica and organic. For certain waters and uses they are practical—cost usually being the deciding factor for this system.

The solids in Table I may vary somewhat according to the residual alkalinity left in the treated water or to the efficiency of the treating equipment. Internal treatment will produce approximately one pound of sludge per million pounds of water for each part per million of hardness in the original water. The externally treated waters will have an average residual hardness of from one to four parts per million in exchanger treated water and from three to ten parts per million in lime-soda softened water. The soluble silica in the boiler water will be somewhat less with internal, lime-soda, or lime-exchanger methods than with exchangers alone.

Waters that have been externally treated may still require some additional treatment to prevent scale, corrosion, foaming, or excessive alkalinity in the boilers or auxiliary equipment. This is especially the case with higher pressures and ratings.

[See General Discussion, p. 1082.—ED.]

GENERAL DISCUSSION

Mr. C. M. Joyce.[1]—In my experience with industrial waters and their treatment for use in the nitrate plastics industry, it is necessary to get as low as 0.01 ppm. iron and not over 0.002 ppm. manganese. When Mr. Miller says that 0.1 ppm. of iron is present does he mean that that was the amount before purification?

Mr. L. B. Miller.[2]—In the manufacture of fine papers, you can use water up to 0.1 ppm. in many cases. It is desirable to go below that, especially in the plastics products that you refer to. It is well known that you do have to have water of far lower iron and manganese content for plastics of some types than you do in the manufacture of paper products. But it seems as though in the treatment of pulp, particularly the washing of the pulp, the iron is adsorbed, and even though you have very low iron, in the water it builds up and up until you actually get quite an undesirable effect in the pulp.

Mr. Joyce.—Well, the water we purified had only 0.1 ppm. of iron and we have to bring it down to 0.01 ppm. to use it.

Mr. Miller.—In the treatment of the water to remove iron, it is quite difficult, as you know, to get it down to that concentration of iron; as a matter of fact, one tenth is moderately hard to obtain, although it can be done, and it is much easier if you do not have to reduce the iron content of the water to below 0.2 to 0.3 ppm.; but in the case of high-grade papers, it would probably become too expensive to decrease the iron down as low as you need to have it but this is advantageous.

Mr. William Stericker.[3]—In connection with the statement on the hardness, I did not understand Mr. Miller to bring out one point which I think is important. High bicarbonate content often interferes with sizing by requiring much larger amounts of alum.

I also raise the point here that I do not think it is objectionable to have the amounts of silica that were stated. I agree that it is taken up in the pulp, but this is advantageous.

Mr. Miller.—In regard to your latter point, in my paper it is stated that even 37 ppm. of silica probably would not cause an undesirable effect, although there was a possibility that under certain conditions, you might get a slightly undesirable effect. Actually, I don't know precisely what the limit is. We were not able to determine that from the questionnaires and from the information that we obtained from the industry. All we could get was a rather general idea on silica, because it is one of the things that isn't particularly undesirable and therefore it has not been investigated very closely. The presence of silica in process water is not especially undesirable in the manufacture of fine papers, unless present in considerable quantities. In the washing of high-grade pulps, however, silica is adsorbed. This increases the ash content of the pulp and this is undesirable.

---

[1] Chemical Engineer, E. I. du Pont de Nemours & Co. Inc., Arlington, N. J.

[2] Chemical Engineer, Consulting Div., W. H. & L. D. Betz, Philadelphia, Pa.

[3] Development Chemist, Chemical Dept., Philadelphia Quartz Co., Philadelphia, Pa.

Now, take iron; of course, we know pretty well where we stand there.

Regarding the effect of high bicarbonate content, perhaps it would have been better if I had stated that it increased the usage of chemicals and included both alum and sizing. I revert to sizing because sizing, of course, is much more expensive than alum, and alum is comparatively cheap, but it is perfectly true that a high bicarbonate water requires both more sizing and more alum in it.

MR. ROBERT C. ADAMS[4] (*presented in written form*).—This discussion has provided a framework which can be developed into a system of classification suitable to the need of Committee D-19 and the Society. This need is for a method by which both the similarities and differences among various waters can be shown in an understandable way. No two waters are identical but the treatment of each water for each purpose must not always be custom designed.

Mr. Collins has selected a representative group of waters based upon the six ions considered. This group could be enlarged to include some unusual waters but I think very few additions will be desired. The simplicity and usefulness of the classification will suffer if the number of specimens becomes so large that they must be grouped instead of standing as individuals. Most of the variants will introduce problems of one or a few additional constituents. For instance iron, or color, or silica might be an additional constituent of any of these waters and the treatment problems which they introduce should be dealt with separately in discussion of the applications which they affect.

Mr. Miller's paper is of exactly the type required to fill out the framework and vitalize the proposed system of classification. It does not presume or attempt to provide complete instructions for water treatment in the field considered but it does give a clear statement of the problems to be expected from use of the specimen waters and the special additional considerations involved in use of water for paper making.

Mr. Holmes' and Mr. Hall's papers, especially the latter, show that no untreated natural waters can be expected to be completely satisfactory for steam generation. The nature and cost of the reconstitution and treatment of the several specimen waters varies not only with their composition but with many other factors than the operating pressure dividing the two papers. This is too complex a problem for summary treatment but mere listing of the variables involved is valuable.

The treatment of various waters for their manifold uses is so complex that exact instructions for the use of all waters for specific applications can scarcely be provided in any system of classification or any manual. Certainly Committee D-19 does not hope to provide *Everyman's Water Consultant* for publication by the Society. Because that task is too forbidding we should not shrink from the lesser one of indicating the general nature of water treatment and the applicability of water types to certain uses. The effort to make the problems of water use and treatment intelligible to the layman and the beginner does not derogate the responsibility and skill of the specialist, for whom there is no substitute. The specialist, however, should avoid the attitude that his esoteric knowledge cannot be understood by the uninitiated lest more articulate scientists displace him as scientists have always displaced magicians.

---

[4] Assistant Head of Chemical Laboratory, U.S. Naval Engineering Experiment Station, Annapolis, Md.

The framework of a system of classification has been erected and this group profitably can spend considerable time in completing the structure begun today.

Mr. R. T. Sheen[5] (*presented in written form*).—Mr. Collins' selection of typical analyses for classification with reference to industrial use has been made primarily with reference to the distribution of population in the United States, and he points out that these analyses represent roughly the composition of public water supplies used by "about 45 per cent of the total population of the cities of the United States that have more than 20,000 inhabitants."

The use of water for industrial purposes does not necessarily follow population concentrations, and, in fact, is hardly compatible with the distribution of population. Two examples of industrial waters not illustrated in the typical analyses given will serve to illustrate this point. There is no typical analysis of waters such as found in the states of Washington and Oregon, with high silica but low total dissolved solids, with silica forming 30 to 50 per cent of the total dissolved solids. There is, however, a huge industrial use of this water by the paper mills in these states. A single moderately sized paper mill may require 10,000,000 gal. of water per day, sufficient for a population for domestic requirements of 100,000 people, and it will not take many paper mills to add up to a water demand comparable to a population far in excess of that found in those two states. Such waters should be considered in an industrial classification.

The second type of water not illustrated is that found in the city of Pittsburgh and at the point of confluence of the Monongahela and Allegheny Rivers forming the Ohio River. It has been reported that due to the heavy industrial load in this section, the entire contents of these rivers are used several times over by the industries bordering on these streams, a tremendous industrial load in ratio to the population, a water of medium hardness but very low alkalinity. The ratio of industrial use to population, for example, will be many times that illustrated by analysis No. 1 on the New York City supply, where the principal load is purely a domestic load and industrial load to domestic load a small fraction of that found in the Ohio Valley section.

While the above comments have been made with particular reference to the typical analyses as presented, I believe there is a serious question as to whether this is the correct approach to the problem, referring to any typical analysis. The possible permutations and combinations of factors in an analysis are legion. It is not possible to use as a yardstick the actual combination of ions—as anyone versed in water technology will never say that a certain water is type 2, or 8, without qualifying the opinion with reference to variations in the content of certain individual ions, or the effect of these particular constituents or a group of constituents to a particular use. Each author that has dealt with a phase of this subject, in considering his subject, has dealt with the limitations on ions, or groups of ions, or characteristics based on these constituents. What is therefore needed is a classification system that will give the necessary yardsticks for evaluating the behavior of water in a given application or in a given process. This cannot be done by considering composite water analyses, but must be a consideration of the limits on those ions or constituents or qualities that directly affect the use of the particular water in the particular process. Such waters as listed may then be used as illustrative of the application of these fundamental standards of classification—but these fundamental standards are first necessary—typical analyses should come later. This committee cannot hope and should not attempt more than a general classification of waters—the final interpretation of a water analysis for its application to a given process is the business of those specializing in water technology and with an intimate knowledge of the subject. To attempt more than a general classification would be to contribute to the confusion of the subject rather than to the clarification.

---

[5] Associate Director, Consulting Div., W. H. & L. D. Betz, Philadelphia, Pa.

TABLE I—SUGGESTED CLASSIFICATION SYSTEM FOR INDUSTRIAL WATERS.

1. Classification for General Industrial Use:
    - A. Corrosivity:
        - (1) At temperature as received.
        - (2) At elevated temperatures.
    - B. Scale or Deposit-Forming Characteristics:
        - (1) At temperature as received.
        - (2) At elevated temperatures.
    - C. Drinking and Sanitary Use:
2. Classification for Treatment Methods:
    - A. Exchange Materials:
        - (1) Zeolites, greensand and synthetic.
        - (2) Carbonaceous exchangers.
        - (3) Resins.
    - B. Lime and Soda Softeners, Hot and Cold.
    - C. Clarification and Color Removal.
    - D. Evaporation (other than in boilers).
3. Classification for Use as Boiler Feed Water:
    - A. Characteristics of Boiler Feed Water. Effect on
        - (1) Feed water lines
        - (2) Heaters
        - (3) Economizers
        - (4) Regulators and other appurtenances before entry to boiler.
    - B. Characteristics of Boiler Waters:
        - (1) Limits on solids, dissolved and suspended.
        - (2) Limits on ions and other constituents.
        - (3) Effect of temperature.
    - C. Characteristics of Steam and Condensate: Effect on
        - (1) Steam lines.
        - (2) Turbines.
        - (3) Condensers
        - (4) Returned condensate lines.
4. Classification for Use by Industry and by Process:
    - A. Paper
    - B. Textile
    - C. Breweries and Distilleries
    - D. Tanneries
    - E. Food
    - F. Chemical Process
    - G. Other Uses

The question next arises as to what simple method of classification can be of service. Perhaps the general outline in Table I could serve as a starting point, with what modifications as may appear necessary or desirable following some study.

Classification according to some such general system as shown above is a fundamental approach to the problem. For example, there are many industrial users of water who are interested only in the general classification as given under Section 1, that is, will the water corrode, will it form scale deposits, and is it fit to drink? There have been considerable data published in the course of the past few years that will permit evaluation of waters according to such standards. The work of Langelier and others will be helpful in this respect. Certain Treasury standards are already available, to which reference can be made in standardizing on the potability of a water supply. Most of the waters shown in the various typical analyses could be either corrosive or scale-forming, depending on the pH value, and it is the behavior of a certain group of constituents that will determine these certain characteristics. It should not prove too great a task for this committee to define yardsticks that can be applied in classification of a water for general industrial use according to these characteristics.

The second classification suggested is for treatment methods. Certain waters are suitable for zeolite softening as received, others must be conditioned and limits may be defined for the pH value, limitations on anion or cation content, or general classification made defining the general characteristics required before a water can be treated in one of these unit processes of treatment. For example, a raw river supply cannot be treated by base exchange methods prior to removal of the turbidity to below certain defined limits.

The third method of classification is for use as boiler feed water, and in this case the general characteristics can be classified in the three stages in which water is used and in which it is present in the cycle, namely, as the boiler feed water, boiler water, steam and condensate. Limits of concentrations can be defined on ions and on gases or at least certain general broad classifications made that will be of service. This system of classification is fully compatible with the remarks affecting classification made by the two authors writing on the subject of boiler feed water. Any of the typical water analyses would have to be first classified for treatment methods and then further classified following the treatment, according to their characteristics in this third general classification.

The last suggested system of classification is according to the use by industry or by individual process and it is well realized that this covers a very broad field.

Mr. L. B. Miller's paper gives us an excellent approach as to the complexity of this problem applied to the paper industry and here again it will be noted the classification is a question of tolerance as far as individual ions constituents are concerned. Certain generalizations are possible for different types of paper to be manufactured. A similar approach can be made in the other industrial classifications as suggested for textile, breweries and distilleries, tanneries, food industries, and other processes. It must again be emphasized that classifications for these several fields can only be general, but it must be a classification according to certain characteristics or constituents of waters, not according to a certain type of water as illustrated by a given analysis.

This committee can render a service to industry by attempting a classification of industrial waters along the lines as suggested or along some similar line, and while this undoubtedly will be a long-time project because of the scope of the work to be covered, if confined to the general system of classification, it should be possible to effect a system that would prove workable in its application.

MR. FRANK N. SPELLER.[6]—After hearing this discussion, I cannot help but feel that we have received a pretty good groundwork for consideration of a very complicated problem. If headway is to be made, I believe it must be somewhat along the lines just indicated by Mr. Sheen in his scheme of classification according to the use to which the water is put. It may be well to start with the problem of cooling and potable domestic water for example and first determine the range of composition that is permissible without treatment.

Chemical or physical treatment would, no doubt, bring into such use some other waters and change the classification.

The typical waters described by Mr. Collins gives us very useful information as to the range of composition in general. However, the problem is so complicated and so bound up with the special requirements of specific industries, that it seems logical to consider the major uses of water separately.

---

[6] Metallurgical Consultant, Pittsburgh, Pa.

The principal objectionable properties of industrial waters are the corrosivity and scale-forming characteristics. These are the problems that were uppermost when the matter of classification was first discussed in Committee D-19.

In conclusion it seems to me that before embarking on a study of classification in general we should survey the water specification limits of the major industries and concentrate on one or two of the most important—forgetting boiler feedwater for the present which has received perhaps more than its share of attention.

MR. A. H. REYNOLDS.[7]—I have a few remarks that are very much along the lines of some of the previous discussion. I believe that if Mr. Holmes or Mr. Hall were given the analyses that Mr. Collins has prepared, they would, based only on those analyses, be able to make a fairly satisfactory evaluation of these waters for certain purposes, but as Mr. Sheen has also brought out, there are certain things that appear lacking in the analyses if these analyses are to be the sole basis for determining the suitability of a water. For example, in Mr. Miller's paper, he pointed out the extreme importance of manganese and iron in waters used in the paper industry, and, of course, we would not get this information from the above analyses.

Mr. Holmes mentioned the various gases, and Mr. Hall went on to point out certain mechanical devices and the bicarbonates or semi-fixed CO_2 as being additional factors of prime importance in determining whether or not a water is suited to do a certain job. Now, I think that those things that are omitted, in some instances at least, are the determining factors. They may be the predominating factors. If an analysis of a water is made and if the suitability of that water for certain purposes is determined by comparison with standard analyses, any other information that is available must not be discarded but must be considered along with that analysis.

Along the line of added information, that we might find valuable, would be something of the history of these waters that Mr. Collins has used as standards. For example, he has told us that he used as No. 1 the Catskill water and No. 3, I believe, was the Lake Michigan water or the Great Lakes water. If we had no other facts about those two supplies other than their source, we would have a great deal of information. We would know how they are used in various industries and whether satisfactory or unsatisfactory results were obtained from their use. If we knew, even without having an analysis of it, that a water was similar to that used in New York City or in the Great Lakes area, we would have valuable information as to its suitability for certain purposes.

I think, therefore, it is somewhat of a mistake to choose as standard waters supplies from limited areas, where there is lacking ample information as to the results of their use in various industries. At least we should choose water from the largest community that would be representative of that type of water, and indicate the community from which it is chosen. I think such information would be valuable.

MR. MILLER.—As a basis for the discussion of the use of industrial water, waters were classified by Committee D-19 on the basis of their more common inorganic constituents. This method of classification was used in the preparation of the several papers presented at this meeting on process water in the pulp and paper industry, and on boiler feedwater for boilers operating over different ranges of pressure. In the discussion which followed the presentation of these several papers, other methods of water classification have been suggested.

---

[7] Directing Chemist, Dearborn Chemical Co., Chicago, Ill.

In this connection I wish to describe the method which has been used by the Water Committee of the Technical Association of the Pulp and Paper Industry in its investigations of the quality of water required for the manufacture of fine papers. The Water Committee first listed those ions and other constituents which are rather commonly found in process water used in the manufacture of fine papers and some of which are known to influence the quality of paper products manufactured through the use of such process waters. Having listed the constituents believed to be of importance, the committee then proceeded to collect pertinent information regarding the concentrations of the various ions and constituents which were found to be satisfactory in water used as process water and the concentrations which had been found by actual operating experience to be detrimental to the quality of the resultant product or to interfere in the operating process.

From the information obtained, permissible limits for the concentrations of the several constituents were determined, and a T.A.P.P.I. Standard was prepared setting forth the maximum permissible limits for these constituents in water used as process water for the manufacture of fine papers. This Standard was published as T.A.P.P.I. Tentative Standard E-600s-44 in the *Paper Trade Journal* for May 25, 1944. I do not recommend this as another method of classification which Committee D-19 of the A.S.T.M. should preferably use for its work on industrial water. I merely wish to point out that this system of classification did work reasonably well in the work on process waters used in the manufacture of fine papers in the investigations of the T.A.P.P.I. Water Committee.

In the work of our T.A.P.P.I. Water Committee we did not consider that the method of classification of water was too important. We did have as our objective the collection of information on water used as process water in the manufacture of fine papers which would permit the paper industry to operate more intelligently in the selection of suitable sources of raw water, in determining what treatment was required in order to fit a selected water for use as process water in the manufacture of fine papers, or to determine whether difficulties encountered in paper manufacture or in the quality of manufactured papers might be due to the quality of the water being used as process water. We believe that we have achieved a certain degree of progress and obtained results which are at least reasonably satisfactory in this connection.

As I understand it, the objective of Committee D-19 in their work on industrial waters is similar to the objective of the T.A.P.P.I. Water Committee in that both committees wish to obtain pertinent information on the quality of water which it is permissible to use for different process purposes. In this connection, I use the term "process purposes" in its widest meaning. This implies that we wish not only to obtain such pertinent information but, what is more important, to place it in the hands of those individuals who can use this information to advantage. The sooner this objective is accomplished, the better. Keeping this objective in mind, the question of the most suitable method of classifying waters becomes a secondary matter. We have had a number of methods of classification suggested. If possible, Committee D-19 should select the best method of classification for its use. The selection of the most suitable method of classifying waters does not appear to the writer to be nearly as important as *to select a method of classification* which is at least reasonably satisfactory and to do so promptly so that rapid progress can be made in the assembly and dissemination of useful and pertinent information which will lead to a more intelligent use of industrial waters. No system of classification will prove to be perfect. The more time that is spent in considering methods of classification, the longer it will be before the real objective of the committee is achieved.

MR. S. F. WHIRL.[8]—In my opinion, it is well nigh impossible to classify natural waters for industrial use on the basis of chemical analysis alone. It seems to me that attempts along this line can lead only to greater confusion than already exists. Any such classification, to be complete, would necessarily require hundreds, or perhaps thousands, of so-called "typical" analyses, much more comprehensive than those given.

Fluctuation in Composition:

Perhaps the greatest drawback to classification of industrial waters, on the basis of chemical analysis, is fluctuation in composition of the source of supply. Presumably, the typical analyses of Tables I and II of Mr. Collins' paper refer to waters of fairly constant composition. However, natural streams supply a large portion of the water used in industry, and, like the Allegheny, Monongahela, and the Ohio Rivers in the Pittsburgh area, they may vary widely in chemical composition. For example, in the accompanying Fig. 1 are plotted the pH and dissolved salts of the Ohio River at the James H. Reed Power Station over a period of several years. It is to be noted that the pH varied from approximately 3.5 to 7.5, and the dissolved salts from 50 ppm. to 400 ppm. How would such waters be classified under this proposed scheme?

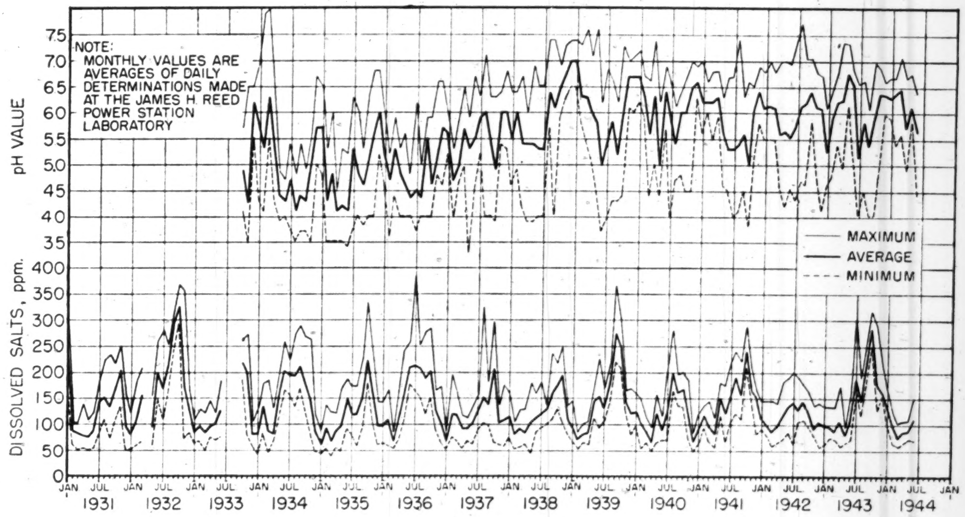


FIG. 1.—Fluctuations in pH Value and Dissolved Salts Concentration of the Ohio River at Pittsburgh, Pa.

---

[8] Chief Chemist, Power Stations Dept., Duquesne Light Co., Pittsburgh, Pa.

Object of Classification:

Let us pause for a moment and consider the objective in classifying waters for industrial use. If it is as Mr. Schroeder suggests, to "judge the suitability of water for a given industrial process by comparing its analysis with the analysis of other waters whose behavior in the process is known," then such a scheme may be of use where no chemical treatment is required; but certainly, where treatment is necessary, the choice of methods should be based on scientific principles, and not on "follow the leader" tactics. Just because a method of water treatment is reported to give satisfactory results does not mean that it is the most logical and best suited for the job. For example, a canvass of industry would show numerous cases where zeolite softening is giving results termed satisfactory, even though some other treatment would have been a more scientific choice, and *vice versa*, Standardization of treatment methods. based on industrial practices, would tend to perpetuate "potato peeling" treatment, and definitely stymie progress.

Furthermore, water quality is seldom a criterion in the location of most industries. Other considerations, such as the source of raw material, the proximity of markets, availability of labor, quantity of water, etc., usually outweigh the water quality problem, and the chemist is forced to do the best he can with the water at hand. While this condition is not the most favorable from the chemist's viewpoint, it is not too alarming, since the science of water treatment has progressed to a point that any water can be conditioned for any industrial use; cost is the principal consideration.

Another obstacle in classifying industrial waters on the basis of analyses is the fact that in most industries, water from one or more sources is usually used for a number of purposes. For instance, in one of our power stations, the same source of supply, river water, is treated in four different ways for four distinct uses: namely, boiler feed; main unit condenser cooling; bearing, compressor, etc., cooling; and sanitary and drinking. At other stations, the river water supply is supplemented by deep well water, in one station for cooling water and at another for sanitary purposes. In many industries, the set-up is much more complicated, making classification of the supply waters of little or no value to similar industries.

Instead of classifying industrial waters on the basis of analyses, it seems to me that Committee D-19 could render more valuable service to industry by classifying the various methods of water treatment on the basis of initial and final analyses, defining the limitations of each method and giving relative cost figures, as Mr. Holmes has done in part in his paper. To a limited degree, manufacturers of water treating equipment use this principle with their own figures in selling their products.

Industry is primarily interested in the final water after treatment, and therefore, Committee D-19 might also consider writing Water Specifications for the various uses in each industry, essentially as Mr. Miller has done for the paper industry and Mr. Hall has initiated in steam generation. A good example of the successful use of such water specifications is the Drinking Water Standards of the United States Public Health Service.

A knowledge of the proper applications and limitations of the various water treating methods and water specifications for various uses in industry would aid both the operating engineer and the specialist.

MR. L. E. DAY[9] (*presented in written form*).—Mr. Collins presented a very simple and practical graphical method of reporting the results of water analyses. However, it has the disadvantage of being unable to show the analyses of waters of widely different total solids contents. If the scale were chosen such that a water of medium solids content would cover a fair portion of the sheet, the constituents of a very pure water would lie so close together that they could not be read. On the other hand those of extremely high concentrations would be off the scale.

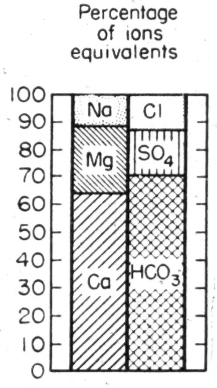


FIG. 2.

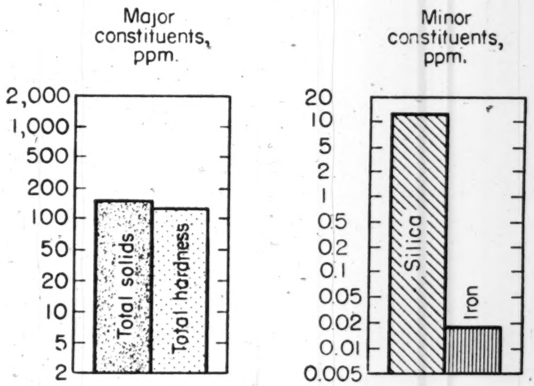


FIG. 3.

I recommend that the committee consider the graphical presentation of the per cent of ions rather than the actual quantities. In this way a form sheet could be prepared with a block of a certain convenient size provided for the graphic chart of the ions. This block would be completely filled irrespective of the total solid concentration of the water. Besides ease of presentation, this method would show the type of water irrespective of the dilution or concentration. A water having a certain graphical pattern as described above could be diluted with distilled water (condensate) or concentrated by evaporation as in a spray pond, provided no solids separated nor carbon dioxide escaped, without changing the pattern.

Water of analysis No. 3 would be presented as calculated below:

Cations	epm.	epm., per cent	epm., per cent, cumulative
Calcium	1.80	64.8	64.8
Magnesium	0.67	24.0	88.8
Sodium and pot.	0.31	11.2	100.0
Total cations	2.78	100.0	.....
Anions			
Bicarbonate	1.95	70.2	70.2
Sulfate	0.46	16.5	86.7
Chloride	0.37	13.3	100.0
Total anions	2.78	100.0	.....

In some cases this chart, as shown in the accompanying Fig. 2, plus the figures for the various quantities in epm. and ppm. will be sufficient. However, when it is desired to present the quantities of the impurities by graphical means, an additional chart (Fig. 3) should be constructed plotted on a logarithmic scale so that waters of all concentrations may be shown. This second graph would show the impurities such as silica, iron and manganese which are not shown on the first chart, together with total solids and total hardness expressed as ppm.

---

[9] Mechanical Apparatus Section, Engineering Dept., Westinghouse Electric Elevator Co., Jersey City, N. J.

MESSRS. L. DREW BETZ[10] AND JOHN J. MAGUIRE[10] (*presented in written form*).—The inclusion of the pH of the various water supplies in the analyses submitted would have been very helpful particularly with respect to the selection of the various means of softening external to the boiler. This is not to be construed as any criticism of Mr. Holmes' paper as we understand he merely discussed the analyses as submitted but this statement should be accepted as a suggestion in the submission of the various water analyses themselves.

Our thoughts on the comments of the various water analyses are in substantial agreement with those expressed by Mr. Holmes and the following remarks should be considered as an addition to these remarks rather than a criticism of the paper. We do wish to briefly discuss the characteristics of several of these supplies primarily to illustrate that when water is considered for use as boiler feedwater it is impossible to state authoritatively what results will be obtained in the way of boiler scale or sludge, corrosion, pitting, intercrystalline cracking, carry over, turbine deposits, steam or return line corrosion and rate of blow down, without possessing at the same time an exact knowledge of the physical and mechanical characteristics of the power plant. The type of boiler, operating pressure, steam temperature, degree of deaeration, the installation of economizers, desuperheaters and blow down heat recovery apparatus are some of the factors possessing a direct bearing on the results obtainable in the treatment of a water supply and all have a bearing in choosing the best method of either external or internal boiler feedwater treatment. In other words the complete treatment to be applied to any water cannot always be selected from the water analysis alone but must be considered together with the equipment and the system in which the water is evaporated.

The type of water available for a plant may, in turn, materially affect the mechanical installation that can be made. For example, if a plant were being considered to operate at 900 psi., 100 per cent make-up and if water as indicated by analysis No. 8 were the only available supply, an inspection of Table B of Mr. Holmes' paper will show that it would not be practical to treat this water by any of the methods of softening tabulated, as the water so treated would develop a total solids content in excess of the allowable limits set by The American Boiler Manufacturers Assn. in their guarantees on steam purity. Approximately 50 per cent blow down would be required with the treated water of lowest solids content. Even if this plant were designed for much lower pressure, the rate of blow down would be excessively high.

In some cases where the dissolved solids content of the water is high, the installation of oversize steam drums, steam washers or separators are required and the choice of the mechanical equipment installed should be selected only after a careful study has been made of the characteristics of the available boiler feedwater. Consequently it is obvious that in the selection of the method of chemically conditioning the boiler feedwater, the power plant designer and the water chemist should work hand in hand in order to produce the plant installation best adaptable to both mechanical and chemical requirements. Unfortunately, too many occasions occur where the water chemist is not consulted until after the mechanical equipment is installed and ready to operate, and obviously it is then too late to include any recommendations of the water chemist.

---

[10] General Manager and Director, Technical Division, respectively, W. H. & L. D. Betz, Philadelphia, Pa.

As stated by Mr. Holmes, examples Nos. 1 to 9 increase in their undesirability as boiler feedwater and without question analysis No. 1 is by far the best.

The chief complicating factor with water No. 2 is, as stated, the color of 200 units. Such waters do possess a tendency to cause foaming, but our experience has shown that if proper internal treatment control is exercised, no carry over will result. The development of special techniques in the control water analyses has been found necessary because of the highly discolored boiler water and the resulting obscuring of titration end points.

The internal treatment of water No. 3 as 100 per cent make-up is feasible although it may not in all cases prove to be the most economical for low-pressure boiler operation. As another example of the effect of plant characteristics, if 90 per cent condensate were returned and only 10 per cent make-up required using a water of the analysis of No. 3, the resulting boiler feedwater would then be superior in every respect to water No. 1 and internal treatment alone is capable of producing excellent results over the entire 100 to 400 psi. range.

The silica content of water No. 4 is particularly disadvantageous for pressures approaching 400 psi. and at higher percentages of make-up water the incorporation of silica removal in the external treatment process would be highly desirable. Because of the natural magnesium and iron content of this supply the lime-soda process would be favored over the zeolite process of water softening.

In respect to water No. 5, it might be added that the natural nitrate content of 13 ppm. as NO_3 is quite likely to be sufficient to develop a satisfactory sodium nitrate—sodium hydroxide ratio for the inhibition of intercrystalline cracking with proper internal treatment of the water, involving a decrease in the bicarbonate content.

As stated, the sodium–hydrogen exchange process is the best method for reducing the solids content of water No. 7. However, no reduction in the silica content would be effected by this process. With a reduction in solids as shown in Table B to 125 ppm., the silica would constitute 17.6 per cent of the dissolved solids. At pressures approaching 400 psi., full advantage of the lowered feedwater solids in permitting a low rate of blow down could not be secured. The silica content of the boiler water rather than the solids content would then be the main factor limiting the blow down rate.

We agree with Mr. Holmes' statement that the externally treated waters will possess an average residual hardness of from 1 to 4 ppm. in exchanger treated water but disagree with his statement that the residual hardness in lime-soda softened water will average 3 to 10 ppm. Hot lime-soda softeners, as usually operated for the treatment of boiler feedwater, show an average hardness which will vary between 15 to 20 ppm. as $CaCO_3$.

We appreciate the opportunity of discussing Mr. Holmes' paper and compliment him on the splendid manner he has handled this subject.

MR. J. A. HOLMES[11] (*by letter*).—Mr. Sheen's discussion, as well as others, are deeply appreciated, however, the original idea of the tables presented by Mr. Collins was not for a definite classification of waters, but rather to act as a guide for the analyst. As pointed out in previous discussions, an analyst may be presented with the problem of analyzing a water, perhaps something which he has never done before. It was my idea that this analyst be given a yardstick or examples of what typical analyses of waters might be so that he would at least have some idea of what to expect.

---

[11] Assistant Vice-President, National Aluminate Corp., Chicago, Ill.

An exaggerated example of the need for such and which actually occurred was the report of an analyst showing calcium and magnesium contents in a water from one of the Great Lakes that was higher than that of sea water. Had the analyst referred to Mr. Collins' table he would have been warned that he had better recheck his analysis, his calculations, or send the water to a laboratory specializing in water analysis.

The purpose of the symposium was to determine whether this table could in some way be used as a basis for the start of a method for classifying water, or whether any method of classification was necessary.

At the 1942 meetings it was the consensus of all but a minority that any classification was either impossible or unnecessary and that the committee should be dissolved, whereas at the 1944 meeting the majority seemed to think that some form of classification of waters would be of value. The classification of deposits seems feasible, therefore, some method should be devised enabling us to classify the waters that cause these deposits.

Typical analyses are still used for metals, coals, etc., and I believe the Collins' table should not be abandoned because it has merit for comparison purposes, which purpose should not be misconstrued with classification as it was never intended to function entirely as such.

MR. W. C. SCHROEDER[12] (*author's closure by letter*).—This session has achieved its purpose of securing expressions of opinion as to whether the classification of industrial waters is desirable and as to how it may best be done. The consensus of thought now appears to be that classification is fine—if an acceptable method can be found.

A diversity of ways of grouping waters systematically has been proposed, ranging from pure comparison with "types" to complete definition of "tolerances." In a sense these ideas are not incompatible for they vary only in the exactitude with which they attempt to set up limits. It is quite probable that some industries which use water have rigorous requirements with respect to certain concentrations of impurities. In many more cases limits cannot be set because of insufficient knowledge or because of lack of agreement.

Mr. Holmes has indicated how difficult a problem classification has been for the Subcommittee. As its new chairman, he inherits the task of evolving a workable standard. The retiring chairman wishes him well.

---

[12] Assistant Chief, Fuels and Explosives Service, U. S. Bureau of Mines.

SUMMARY OF PROCEEDINGS OF THE CINCINNATI SPRING MEETING—SYMPOSIUM ON THE APPLICATIONS OF SYNTHETIC RUBBERS

The fourteenth Spring Meeting of the Society was held in Cincinnati, Ohio, Wednesday, March 2, 1944, in conjunction with the Spring Group Meetings of the A. S. T. M. committees.

The meeting comprised a technical program—Symposium on the Applications of Synthetic Rubbers—presented at a morning and afternoon session. The symposium was sponsored by Committee D-11 on Rubber Products and was developed by the following special committee:

A. W. Carpenter (Chairman), Manager of Testing Laboratories, The B. F. Goodrich Co.
S. Collier, Manager, Inspection and Control Dept., Johns-Manville Corp.
H. L. Ebert, Chief Chemist, Mechanical Goods, The Firestone Tire and Rubber Co.
H. M. Frecker, Jr., Assistant Manager, Mechanical Goods Development, United States Rubber Co.
W. H. Gardner, representing A.S.T.M. Committee E-6 on Papers and Publications.
Oliver M. Hayden, Manager, Rubber Chemicals Division, E. I. du Pont de Nemours and Co., Inc.
J. H. Ingmanson, Vice-President, The Whitney Blake Co.
E. G. Kimmich, Mechanical Goods Development, The Goodyear Tire and Rubber Co.
Irving E. Lightbown, Assistant Manager, Stanco Distributors, Inc.
S. Maner Martin, Jr., Development Manager, Thiokol Corp.
W. J. McCortney, Engineer in Charge of Rubber-Plastics Laboratory, Engineering Dept., Chrysler Corp.
W. D. Parrish, Technical Service Manager, Hycar Chemical Co.
Gerald Reinsmith, Office of the Chief of Ordnance, U. S. Army
G. H. Swart, Research Director, The General Tire and Rubber Co.
T. A. Werkenthin, Bureau of Ships, U. S. Navy

The purpose of this symposium was to make available latest information on properties and applications of the various synthetic rubbers as applied to fields where rubber products are widely used. While for purposes of war security, the complete picture was not permitted to be presented at the symposium, it is felt that the papers represent a great contribution to the existing knowledge of synthetic rubbers. The symposium consisted of the following 14 papers:

Introduction—A. W. Carpenter
The Origin and Development of Synthetic Rubbers—Harry L. Fisher

Physical Testing of Synthetic Rubber Products—L. V. Cooper
The Physical Properties of the Synthetic Rubbers—J. M. Ball and G. C. Maassen
Specifications for Synthetic Rubber Compounds—M. J. De France
The Processing Characteristics of the Synthetic Rubbers and Their Use in the Manufacture of Extruded Products—A. E. Juve
Synthetic Rubber Tires and Inner Tubes—P. M. Torrance
Belting and Hose Made from Synthetic Rubber—W. L. White
The Use of Synthetic Rubbers in Molded Products—M. J. Sanger
Cellular Rubbers—Louis P. Gould
Hard Rubber Products from Synthetic Rubbers—Walter H. Juve
Synthetic Rubbers in the Wire and Cable Industry—R. A. Schatzel
Use of Synthetic Rubber in Footwear—Stanton Glover
Synthetic Rubber Adhesives—Fred J. Wehmer

The chairman at the morning session was J. H. Ingmanson, Vice-President, The Whitney Blake Co. At the afternoon session the presiding officer was Simon Collier, Manager, Inspection and Control Department, Johns-Manville Corp.

There were more than 600 members and guests in attendance at both sessions.

SUBJECT INDEX

VOLUME 44

A

Accelerated Testing.

See **Corrosion; Weathering.**

Additions.

Application of Fly Ash for Lean Concrete Mixes—Harry A. Frederick, 810. Discussion, 819.
The Data on Darex AEA—summarized by H. J. Gilkey. Report of Committee C-1, Appendix, 300.
Proposed Method of Chemical Analysis for Darex AEA in Portland Cement. Report of Committee C-1, Appendix II, 311.
The Reaction of Vinsol Resin as It Affects the Air Entrainment of Portland-Cement Concrete—Charles E. Wuerpel and Albert Weiner. Published in ASTM BULLETIN, No. 130, October, 1944, p. 41. Discussion, p. 43.
Report of Working Committee on Additions. Report of Committee C-1, 299.
Report on Cooperative Studies of Proposed Method of Test for Air Content of Portland-Cement Mortar. Report of Committee C-1, Appendix I, 306.

Adhesives.

Summary of Proceedings of the Cincinnati Spring Meeting—Symposium on the Applications of Synthetic Rubbers, 1095.

Admiralty Metal.

Atmospheric Corrosion. Report of Subcommittee VI, Committee B-3, 224.

Aggregates.

Application of Fly Ash for Lean Conrete Mixes—Harry A. Frederick, 810. Discussion, 819.
A Comparison of Results of Sieving Procedures in Soundness Tests on Maine Sands—Andrew Adams and Horace A. Pratt, 806.
Concrete and Concrete Aggregates. Report of Committee C-9, 336.

Air Entrainment.

The Data on Darex AEA—summarized by H. J. Gilkey. Report of Committee C-1, Appendix, 300.
Entrained Air—Its Effect on the Constituents of Portland Cement Concrete—Henry L. Kennedy, 821. Discussion, 831.
Proposed Method of Chemical Analysis for Darex AEA in Portland Cement. Report of Committee C-1, Appendix II, 311.
The Reaction of Vinsol Resin as It Affects the Air Entrainment of Portland-Cement Concrete—Charles E. Wuerpel and Albert Weiner. Published in ASTM BULLETIN, No. 130, October, 1944, p. 41. Discussion, p. 43.
Report of Working Committee on Additions. Report of Committee C-1, 299.
Report on Cooperative Studies of Proposed Method of Test for Air Content of Portland-Cement Mortar. Report of Committee C-1, Appendix I, 306.
Volumetric Method for Determining the Air Content of Freshly Mixed Concrete—J. C. Pearson. Report of Committee C-9, Appendix, 343. Discussion, 351.

Alloy Steel.

See also **Steel.**
Colorimetric Methods for the Analysis of Ferrous Alloys—Arba Thomas, 769.
Cooperative Study of Effect of Rate of Strain on Tensile Properties of Stainless Sheets. Report of Subcommittee V, Committee A-10, Appendix, 133.

Alloy Steel (*Continued*).
- Correlation of Short- and Long-Time Elevated Temperature Test Methods (Project No. 25). Report of Joint Research Committee on Effect of Temperature on the Properties of Metals, Appendix, II, 186.
- Effect of Temperature on the Properties of Metals. Report of Joint Research Committee, 159.
- Factors Affecting Hardness Relationships in the Range 50 to 250 Brinell—Robert H. Heyer, 1027. Discussion, 1046.
- Filler Metal. Report of Joint Committee, 216.
- Iron-Chromium, Iron-Chromium-Nickel and Related Alloys. Report of Committee A-10, 126.
- Magnetic Properties. Report of Committee A-6, 114.
- Report on Round-Robin Core Loss Testing at High Flux Densities. Committee A-6, 120.
- Study of Effects of Variables on the Creep Resistance of Steels (Project No. 18)—H. C. Cross and W. Simmons. Report of Joint Research Committee on Effect of Temperature on the Properties of Metals, Appendix I, 161.
- The Technical Cohesive Strength of Some Steels and Light Alloys at Low Temperatures—D. J. McAdam, Jr., R. W. Mebs, and G. W. Geil, 593. Discussion, 624.

Alloys, Non-Ferrous.
- See also **Aluminum; Brass; Bronze; Copper; Electrical Resistance and Heating Alloys; Magnesium; Zinc.**
- An Alternate Immersion Test for Aluminum-Copper—R. B. Mears, C. J. Walton, and G. G. Eldredge, 639.
- Atmospheric Corrosion. Report of Subcommittee VI, Committee B-3, 224.
- Chemical Analysis of Metals. Report of Committee E-3, 521.
- Colorimetric Determination of Silicon in Aluminum Alloys—Joseph J. Stumm, 749.
- Colorimetric Methods for the Analysis of Magnesium-Base Alloys—V. A. Stenger, 754.
- Copper and Copper-Alloy Wires for Electrical Conductors. Report of Committee B-1, 218.
- Copper and Copper Alloys, Cast and Wrought. Report of Committee B-5, 243.
- Corrosion of Non-Ferrous Metals and Alloys. Report of Committee B-3, 222.
- Die-Cast Metals and Alloys. Report of Committee B-6, 261.
- Effect of Temperature on the Properties of Metals. Report of Joint Research Committee, 159.
- Electrical-Heating, Electrical-Resistance and Electric-Furnace Alloys. Report of Committee B-4, 240.
- Electrodeposited Metallic Coatings. Report of Committee B-8, 278.
- Evolution of Test Specimen for Non-Ferrous Castings—A. J. Smith, 625. Discussion, 636.
- Light Metals and Alloys, Cast and Wrought. Report of Committee B-7, 266.
- Metallography. Report of Committee E-4, 523.
- Micro-Deformation Under Tension and Compression Loads of Thin Aluminum Alloy Sheets for Aircraft Construction—Georges Welter, 665. Discussion, 682.
- Non-Ferrous Metals and Alloys. Report of Committee B-2, 220.
- A Numerical Rating Method for the Routine Metallographic Examination of Commercial Magnesium Alloys—P. F. George. Published in ASTM BULLETIN, No. 129, August, 1944, p. 35. Discussion, p. 43.
- Quantitative Spectrographic Analysis of Copper Alloys—R. A. Wolfe and Emile J. Jemal. Published in ASTM BULLETIN, No. 129, August, 1944, p. 45. Discussion, p. 52.
- Recommendations Affecting Standards for Copper and Copper Alloys, Cast and Wrought. Report of Committee B-5, Appendix, 250.
- Recommendations Affecting Standards for Light Metals and Alloys, Cast and Wrought. Report of Committee B-7, Appendix, 270.
- Short-Time Tests of Solders and Soldered Joints—J. A. Kies and W. F. Roeser, 691. Discussion, 707.
- Spectrographic Analysis. Report of Committee E-2, 519.

Aluminum.

An Alternate Immersion Test for Aluminum-Copper Alloys—R. B. Mears, C. J. Walton, and G. G. Eldredge, 639.
Atmospheric Corrosion. Report of Subcommittee VI, Committee B-3, 224.
Colorimetric Determination of Silicon in Aluminum Alloys—Joseph J. Stumm, 749.
Die-Cast Metals and Alloys. Report of Committee B-6, 260.
Factors Affecting Hardness Relationships in the Range 50 to 250 Brinnell—Robert H. Heyer, 1027. Discussion, 1046.
Filler Metal. Report of Joint Committee, 216.
Light Metals and Alloys, Cast and Wrought. Report of Committee B-7, 266.
Micro-Deformation Under Tension and Compression Loads of Thin Aluminum Alloy Sheets for Aircraft Construction—Georges Welter, 665. Discussion, 682.
Recommendations Affecting Standards for Light Metals and Alloys, Cast and Wrought. Report of Committee B-7, Appendix, 270.
Report on Inspections of Metallic Coatings on Hardware, etc. Report of Subcommittee VIII, Committee A-5, 96.
The Technical Cohesive Strength of Some Steels and Light Alloys at Low Temperatures—D. J. McAdam, Jr., R. W. Mebs, and G. W. Geil, 593. Discussion 624.

Amaloy Coatings.

Report on Inspections of Metallic Coatings on Hardware, etc. Report of Subcommittee VIII, Committee A-5, 96.

Analytical Chemistry.

See **Chemical Analysis; Spectrographic Analysis.**
(Methods of analysis, testing, etc., are also indexed under the materials and subjects covered by them.)

Annapolis Exposure Tests.

Record of failures in atmospheric tests at Annapolis of No. 22-gage copper-bearing and non-copper-bearing corrugated black sheets, Report of Committee A-5, 89.

Annual Meeting.

Annual Report of the Executive Committee, 39.
Summary of Proceedings of the Forty-seventh Annual Meeting, 1.

Anodic Coatings.

Light Metals and Alloys, Cast and Wrought. Report of Committee B-7, 266.

Anthracite.

See **Coal.**

Apparatus, Laboratory.

Methods of Testing. Report of Committee E-1, 515.

Asbestos.

Textile Materials. Report of Committee D-13, 474.
Recommendations Affecting Standards for Textile Materials. Report of Committee D-13. Appendix, 481.

Ash Admixture.

Application of Fly Ash for Lean Concrete Mixes—Harry A. Frederick, 810. Discussion, 819.

Askarels.

Electrical Insulating Materials. Report of Committee D-9, 422.
Investigation of Test Procedures for Dielectric Strength of Liquid Insulation. Report of Committee D-9, Appendix II, 429.
Proposed Methods of Test for Gas Content of Insulating Oil. Report of Committee D-9, Appendix III, 450.

Asphalt.

Bituminous Waterproofing and Roofing Materials. Report of Committee D-8, 417.
Road and Paving Materials. Report of Committee D-4, 401.

Atmospheric Exposure.

See **Corrosion; Weathering.**

Autoclave Test.

Comparative Tests of 52 Brands of Portland Cement from 15 Countries—Eugene V. Barrett, 793. Discussion, 802.
Use of the Autoclave for Testing Lime. Report of Special Subcommittee, Committee C-7, 320.

B

Beams.

The Effect of Discontinuities on the Natural Frequency of Beams—Philip G. Kirmser, 897.

Bearing Metal.

Non-Ferrous Metals and Alloys. Report of Committee B-2, 220.

Bearings.

Metal Powders and Metal Powder Products. Report of Committee B-9, 292.

Belting.

Summary of Proceedings of the Cincinnati Spring Meeting—Symposium on the Applications of Synthetic Rubbers, 1095.

Bend Test.

Proposed Specifications for Lead-Alloy (Hot-Dip) Coated Steel Sheets. Report of Committee A-5, Appendix, 110.

Benzene.

Industrial Aromatic Hydrocarbons. Report of Committee D-16, 490.

Bibliography.

Bibliography of Photoelectric Spectrophotometric Methods of Analysis for Inorganic Ions—J. W. Stillman, 740.
Literature on Steel K20, 212. Joint Research Committee Report Appendix II

Bituminous Coal.

See **Coal.**

Bituminous Materials.

See **Asphalt; Petroleum Products; Roofing Materials; Waterproofing Materials.**

Boiler Feedwater.

See also **Water.**
Boiler Feedwater Studies. Joint Research Committee, 504.
Water for Industrial Uses. Report of Committee D-19, 500.

Bolts.

Report on Inspections of Metallic Coatings on Hardware, etc. Report of Subcommittee VIII, Committee A-5, 96.

Bomb Test.

Proposed Method of Test for Potential Gum in Aviation Gasoline. Report of Committee D-2, Appendix IV, 393.

Boxes.

Paper and Paper Products. Report of Committee D-6, 411.

Brass.

Atmospheric Corrosion. Report of Subcommittee VI, Committee B-3, 224.
Colorimetric Methods for the Analysis of Copper-Base Alloys and Refined Lead—C. Zischkau, 762.
Copper and Copper Alloys, Cast and Wrought. Report of Committee B-5, 243.
Die-Cast Metals and Alloys. Report of Committee B-6, 261.
Factors Affecting Hardness Relationships in the Range 50 to 250 Brinell—Robert H. Heyer, 1027. Discussion, 1046.
Recommendations Affecting Standards for Copper and Copper Alloys, Cast and Wrought. Report of Committee B-5, Appendix, 250.
Short-Time Tests of Solders and Soldered Joints—J. A. Kies and W. F. Roeser, 691. Discussion, 707.

Breaking Strength of Fabrics.

Factors Influencing the Breaking Strength of Army and Navy Fabrics—Werner von Bergen, John C. Hintermaier and Eric Ullman, 916.

Brick.

Manufactured Masonry Units. Report of Committee C-15, 356.
Refractories. Report of Committee C-8, 331.

Brinell Hardness.

See **Hardness Testing.**

Bronze.

See also **Copper.**
Atmospheric Corrosion. Report of Subcommittee VI, Committee B-3, 224.
Colorimetric Methods for the Analysis of Copper-Base Alloys and Refined Lead—C. Zischkau, 762.
Copper and Copper Alloys, Cast and Wrought. Report of Committee B-5, 243.
Evolution of Test Specimens for Non-Ferrous Castings—A. J. Smith, 625. Discussion, 636.
Recommendations Affecting Standards for Copper and Copper Alloys, Cast and Wrought. Report of Committee B-5, Appendix, 250.

Building Brick.

See **Brick.**

C

Cable.

Copper and Copper-Alloy Wires for Electrical Conductors. Report of Committee B-1, 218.

Cadmium Coatings.

Report on Inspections of Metallic Coatings on Hardware, etc. Report of Subcommittee VIII, Committee A-5, 96.

Calibration.

Characteristics of the Tuckerman Strain Gage—Bruce L. Wilson, 1017.

Calorized Coatings.

Report on Inspections of Metallic Coatings on Hardware, etc. Report of Subcommittee VIII, Committee A-5, 96.

Camouflage Type Finishes.

Measurement of Fading Resistance of Camouflage Type Finishes by Accelerated Weathering—J. W. Iliff and L. B. Darrall 905.

Carbon-Molybdenum Steel.

See **Alloy Steel.**

Cast Iron.

Cast Iron. Report of Committee A-3, 85.
Summary of Proceedings of Round-Table Discussion on Centrifugal Castings, N. L. Mochel, 779.

Castings.

See **Alloy Steel; Aluminum; Brass; Bronze; Cast Iron; Copper; Die Castings; Magnesium; Malleable Iron; Steel.**

Cellular Rubber.

Summary of Proceedings of the Cincinnati Spring Meeting—Symposium on the Applications of Synthetic Rubbers, 1095.

Cement.

Cement. Report of Committee C-1, 294.
Comparative Tests of 52 Brands of Portland Cement from 15 Countries—Eugene V. Barrett, 793. Discussion, 802.
The Data on Darex AEA—summarized by H. J. Gilkey. Report of Committee C-1, Appendix, 300.
The Effects of Certain Variations in Consistency and Curing Conditions on the Compressive Strengths of Cement-Lime Mortars—G. J. Fink, 780. Discussion, 788.
Proposed Method of Chemical Analysis for Darex AEA in Portland Cement. Report of Committee C-1, Appendix II, 311.
Report of Working Committee on Additions. Report of Committee C-1, 299.
Report on Cooperative Studies of Proposed Method of Test for Air Content of Portland-Cement Mortar. Report of Committee C-1, Appendix I, 306.
Summary of Proposed Revisions in Methods of Chemical Analysis of Portland Cement. Report of Committee C-1, Appendix III, 313.
Thermal Insulating Materials. Report of Committee C-16, 358.
Use of the Autoclave for Testing Lime. Report of Special Subcommittee, Committee C-7, 320.
Volumetric Method for Determining the Air Content of Freshly Mixed Concrete—J. C. Pearson. Report of Committee C-9, Appendix, 343. Discussion, 351.

Cemented Carbides.

See **Metal Powders.**

Centrifugal Castings.

Summary of Proceedings of Round-Table Discussion on Centrifugal Castings, N. L. Mochel, 779.

Charpy Impact.

See **Impact Testing.**

Chemical Analysis.

Cement. Report of Committee C-1, 294.
Chemical Analysis of Metals. Report of Committee E-3, 521.
Comparative Tests of 52 Brands of Portland Cement from 15 Countries—Eugene V. Barrett, 793. Discussion, 802.
Proposed Method of Chemical Analysis for Darex AEA in Portland Cement. Report of Committee C-1, Appendix II, 311.
Spectrographic Analysis. Report of Committee E-2, 519.
Summary of Proposed Revisions in Methods of Chemical Analysis of Portland Cement. Report of Committee C-1, Appendix III, 313.
Symposium on Analytical Colorimetry and Photometry:
  Opening Remarks—G. E. F. Lundell, 709.
  Introduction—Trends in Analytical Chemistry—B. L. Clarke, 710.
  Colorimetric Analysis and Beer's Law—John L. Hague, 712.
  Filter Photometers—A. E. Ruehle, 718.
  Glass Photometric Filters—O. A. Gage, 720.
  Spectrophotometers—Kasson S. Gibson, 725.
  The Chemistry in Colorimetry—M. G. Mellon, 733.
  Bibliography of Photoelectric Spectrophotometric Methods of Analysis for Inorganic Ions—J. W. Stillman, 740.
  Colorimetric Determination of Silicon in Aluminum Alloys—Joseph J. Stumm, 749.
  Colorimetric Methods for the Analysis of Magnesium-Base Alloys—V. A. Stenger, 754.
  Colorimetric Methods for the Analysis of Copper-Base Alloys and Refined Lead—C. Zischkau, 762.
  Colorimetric Methods for the Analysis of Ferrous Alloys—Arba Thomas, 769.

Chromium.

Electrodeposited Metallic Coatings. Report of Committee B-8, 278.

Chromium-Nickel Alloys.

See **Alloy Steel; Electrical Resistance and Heating Alloys.**

Clad Steel.

See **Corrosion-Resisting Alloy Steels.**

Classification of Waters.

Round-Table Discussion on Organizing the Classification of Industrial Waters:
  Introduction—W. C. Schroeder, 1051.
  Typical Water Analyses for Classification with Reference to Industrial Use—W. D. Collins, 1057.
  The Use of Selected Waters in Pulp and Paper Manufacture—Lewis B. Miller, 1061.
  Treatment of Various Types of Waters for Operating Pressures above 400 psi.—R. E. Hall, 1069.
  Classification of Feedwater for Boilers Operating Between 100–400 psi.—J. A. Holmes, 1078.
  General Discussion, 1082.

Coal.

Coal and Coke. Report of Committee D-5, 406.

Coated Fabrics.

See **Rubber Products.**

Cohesive Strength.

The Technical Cohesive Strength of Some Steels and Light Alloys at Low Temperatures—D. J. McAdam, Jr., R. W. Mebs, and G. W. Geil, 593. Discussion 624.

Coke.

Coal and Coke. Report of Committee D-5, 406.

Colorimetry.

Symposium on Analytical Colorimetry and Photometry:
  Opening Remarks—G. E. F. Lundell, 709.
  Introduction—Trends in Analytical Chemistry—B. L. Clarke, 710.
  Colorimetric Analysis and Beer's Law—John L. Hague, 712.
  Filter Photometers—A. E. Ruehle, 718.
  Glass Photometric Filters—O. A. Gage, 720.
  Spectrophotometers—Kasson S. Gibson, 725.
  The Chemistry in Colorimetry—M. G. Mellon, 733.
  Bibliography of Photoelectric Spectrophotometric Methods of Analysis for Inorganic Ions—J. W. Stillman, 740.
  Colorimetric Determination of Silicon in Aluminum Alloys—Joseph J. Stumm, 749.
  Colorimetric Methods for the Analysis of Magnesium-Base Alloys—V. A. Stenger, 754.
  Colorimetric Methods for the Analysis of Copper-Base Alloys and Refined Lead—C. Zischkau, 762.
  Colorimetric Methods for the Analysis of Ferrous Alloys—Arba Thomas, 769.

Compressed Wood.

Fatigue Tests on Compressed and Impregnated Laminated Wood—Albert G. H. Dietz and Henry Grinsfelder. Published in ASTM BULLETIN, No. 129, August, 1944, p. 31. Discussion, 34.

Compression Testing.

Comparative Tests of 52 Brands of Portland Cement from 15 Countries—Eugene V. Barrett, 793. Discussion, 802.
The Effects of Certain Variations in Consistency and Curing Conditions on the Compressive Strengths of Cement-Lime Mortars—G. J. Fink, 780. Discussion, 788.
The Measurement of Concrete Strength by Embedded Pull-Out Bars—Bailey Tremper, 880.
Micro-Deformation Under Tension and Compression Loads of Thin Aluminum Alloy Sheets for Aircraft Construction—Georges Welter, 665. Discussion, 682.
Precision Indices for Compression Tests of Companion Concrete Cylinders—S. P. Wing, Water H. Price, and Clemeunt T. Douglass, 839. Discussion, 852.
Short-Time Static Tests and Creep Tests of a Paper Laminated Plastic—W. N. Findley and W. J. Worley, 949. Discussion, 967.
Some Properties of Concrete Under Sustained Combined Stresses—C. Martin Duke and Harmer E. Davis, 888.
Tests Comparing the Modulus of Elasticity of Portland Cement Concrete as Determined by the Dynamic (Sonic) and Compression (Secant at 1000 psi.) Methods—Thomas E. Stanton. Published in ASTM BULLETIN, No. 131, December, 1944, p. 17. Discussion, p. 20.

Concrete.

Application of Fly Ash for Lean Concrete Mixes—Harry A. Frederick, 810. Discussion, 819.
Concrete and Concrete Aggregates. Report of Committee C-9, 336.
The Data on Darex AEA—summarized by H. J. Gilkey. Report of Committee C-1, Appendix, 300.
The Effect of Discontinuities of the Natural Frequency Beams—Philip G. Kirmser, 897.
Entrained Air—Its Effect on the Constituents of Portland Cement Concrete—Henry L. Kennedy, 821. Discussion, 831.
Fourth Sanford E. Thompson Award. Summary of Proceedings of the Forty-seventh Annual Meeting, 26. Report of Committee C-9, 336.
Manufactured Masonry Units. Report of Committee C-15, 356.
The Measurement of Concrete Strength by Embedded Pull-Out Bars—Bailey Tremper, 880.
Precision Indices for Compression Tests of Companion Concrete Cylinders—S. P. Wing, Walter H. Price, and Clemeunt T. Douglass, 839. Discussion, 852.
The Reaction of Vinsol Resin as It Affects the Air Entrainment of Portland-Cement Concrete—Charles E. Wuerpel and Albert Weiner. Published in ASTM BULLETIN, No. 130, October, 1944, p. 41. Discussion, p. 43.

Concrete (*Continued*).
Report of Working Committee on Additions. Report of Committee C-1, 299.
Report on Cooperative Studies of Proposed Method of Test for Air Content of Portland-Cement Mortar. Report of Committee C-1, Appendix I, 306.
Some Properties of Concrete Under Sustained Combined Stresses—C. Martin Duke and Harmer E. Davis, 888.
Tests Comparing the Modulus of Elasticity of Portland Cement Concrete as Determined by the Dynamic (Sonic) and Compression (Secant at 1000 psi.) Methods—Thomas E. Stanton. Published in ASTM BULLETIN, No. 131, December, 1944, p. 17. Discussion, p. 20.
Volumetric Method for Determining the Air Content of Freshly Mixed Concrete—J. C. Pearson. Report of Committee C-9, Appendix, 343. Discussion, 351.

Conditioning.
Electrical Insulating Materials. Report of Committee D-9, 422.
Methods of Testing. Report of Committee E-1, 515.

Consistency.
Comparative Tests of 52 Brands of Portland Cement from 15 Countries—Eugene V. Barrett, 793. Discussion, 802.
The Effects of Certain Variations in Consistency and Curing Conditions on the Compressive Strengths of Cement-Lime Mortars—G. J. Fink, 780. Discussion, 788.
Methods of Testing. Report of Committee E-1, 515.

Contact Metals.
Electrical-Heating, Electrical-Resistance, and Electric-Furnace Alloys. Report of Committee B-4, 240.

Containers.
Paper and Paper Products. Report of Committee D-6, 411.

Conversion Table.
Conversion Tables for Petroleum Oils of Metric Tons in Vacuo to Long and Short Tons in Air. Report of Committee D-2, Appendix I, 381.
Factors Affecting Hardness Relationships in the Range 50 to 250 Brinell—Robert H. Heyer, 1027. Discussion, 1046.

Copper.
An Alternate Immersion Test for Aluminum-Copper Alloys—R. B. Mears, C. J. Walton, and G. G. Eldredge, 639.
Atmospheric Corrosion. Report of Subcommittee VI, Committee B-3, 224.
Colorimetric Methods for the Analysis of Copper-Base Alloys and Refined Lead—C. Zischkau, 762.
Copper and Copper Alloys, Cast and Wrought. Report of Committee B-5, 243.
Factors Affecting Hardness Relationships in the Range 50 to 250 Brinell—Robert H. Heyer, 1027. Discussion, 1046.
Non-Ferrous Metals and Alloys. Report of Committee B-2, 220.
Performance Tests, atmospheric exposure tests of electroplated coatings on steel. Report of Subcommittee II, Committee B-8, 280.
Quantitative Spectrographic Analysis of Copper Alloys—R. A. Wolfe and Emile J. Jemal. Published in ASTM BULLETIN, No. 129, August, 1944, p. 45. Discussion, p. 52.
Recommendations Affecting Standards for Copper and Copper Alloys, Cast and Wrought. Report of Committee B-5, Appendix, 250.

Copper-Bearing Steel.
Corrosion of Iron and Steel. Report of Committee A-5, 87.
Field Tests of Metallic Coatings. Report of Subcommittee VIII, Committee A-5, 92.
Record of failures in atmospheric tests at Annapolis of No. 22-gage copper-bearing and non-copper-bearing corrugated black sheets, Report of Committee A-5, 89.
Report on Inspections of Metallic Coatings on Hardware, etc. Report of Subcommittee VIII, Committee A-5, 96.

Copper Wire.
Copper and Copper-Alloy Wires for Electrical Conductors. Report of Committee B-1, 218.

Core Loss.

See **Magnetic Testing.**

Corrosion.

See also **Weathering.**
An Alternate Immersion Test for Aluminum-Copper Alloys—R. B. Mears, C. J. Walton, and G. G. Eldredge, 639.
Atmospheric Corrosion. Report of Subcommittee VI, Committee B-3, 224.
Basic Requirements in the Standardization of the Salt Spray Corrosion Test—Leo J. Waldron, 654. Discussion, 663.
Corrosion of Iron and Steel. Report of Committee A-5, 87.
Corrosion of Non-Ferrous Metals and Alloys. Report of Committee B-3, 222.
Die-Cast Metals and Alloys. Report of Committee B-6, 261.
Electrodeposited Metallic Coatings. Report of Committee B-8, 278.
Field Tests of Metallic Coatings. Report of Subcommittee VIII, Committee A-5, 92.
Iron-Chromium, Iron-Chromium-Nickel and Related Alloys. Report of Committee A-10, 126.
Light Metals and Alloys, Cast and Wrought. Report of Committee B-7, 266.
Performance Tests, atmospheric exposure tests of electroplated lead coatings on steel. Report of Subcommittee II, Committee B-8, 280.
Record of failures in atmospheric tests at Annapolis of No. 22-gage copper-bearing and non-copper-bearing corrugated black sheets, Report of Committee A-5, 89.
Report on Inspections of Metallic Coatings on Hardware, etc. Report of Subcommittee VIII, Committee A-5, 96.

Corrosion-Resisting Alloy Steels.

See also **Alloy Steels.**
Cooperative Study of Effect of Rate of Strain on Tensile Properties of Stainless Sheets. Report of Subcommittee V, Committee A-10, Appendix, 133.
Iron-Chromium, Iron-Chromium-Nickel and Related Alloys. Report of Committee A-10, 126.

Cotton.

See also **Textiles.**
Recommendations Affecting Standards for Textile Materials. Report of Committee D-13, Appendix, 481.
Textile Materials. Report of Committee D-13, 474.

Crankcase Oils.

See **Lubricants; Petroleum Products.**

Creep Tests.

See also **Temperature, Effect of.**
Correlation of Short- and Long-Time Elevated Temperature Test Methods (Project No 25). Report of Joint Research Committee on Effect of Temperature on the Properties of Metals, Appendix II, 186.
Effect of Temperature on the Properties of Metals. Report of Joint Research Committee, 159.
Short-Time Static Tests and Creep Tests of a Paper Laminated Plastic—W. N. Findley and W. J. Worley, 949. Discussion, 967.
Some Properties of Concrete Under Sustained Combined Stresses—C. Martin Duke and Harmer E. Davis, 888.
Study of Effects of Variables on the Creep Resistance of Steels (Project No. 18)—H. C. Cross and W. Simmons. Report of Joint Research Committee on Effect of Temperature on the Properties of Metals, Appendix I, 161.

Curing Conditions.

The Effects of Certain Variations in Consistency and Curing Conditions of the Compressive Strengths of Cement-Lime Mortars —G. J. Fink, 780. Discussion, 788.

D

Dampproofing.

See **Waterproofing Materials.**

Darex AEA.

The Data on Darex AEA—summarized by H. J. Gilkey. Report of Committee C-1, Appendix, 300.
Proposed Method of Chemical Analysis for Darex AEA in Portland Cement. Report of Committee C-1, Appendix II, 311.

Darex AEA (*Continued*).

Report of Working Committee on Additions. Report of Committee C-1, 299.

Definitions of Terms.

Nomenclature and Definitions. Report of Committee E-8, 531.

Die Castings.

Die-Cast Metals and Alloys. Report of Committee B-6, 260.

Dielectric Strength.

Investigation of Test Procedures for Dielectric Strength of Liquid Insulation. Report of Committee D-9, Appendix II, 439.

Dipentene.

Naval Stores. Report of Committee D-17, 492.

Durability.

See **Weathering.**

Duralumin.

See **Aluminum.**

Dynamic Testing.

The Effect of Discontinuities on the Natural Frequency of Beams—Philip G. Kirmser, 897.

Tests Comparing the Modulus of Elasticity of Portland Cement Concrete as Determined by the Dynamic (Sonic) and Compression (Secant at 1000 psi.) Methods—Thomas E. Stanton. Published in ASTM BULLETIN, No. 131, December, 1944, p. 17. Discussion, p. 20.

E

Effect of Specimen Size.

See **Test Specimen.**

Effect of Temperature.

See **Temperature, Effect of.**

Elasticity.

See **Compression Testing; Tension Testing.**

Elastomers.

See **Rubber Products.**

Electric-Furnace Alloys.

Electrical-Heating, Electrical-Resistance and Electric-Furnace Alloys, Report of Committee B-4, 240.

Electrical Insulating Materials.

Electrical Insulating Materials. Report of Committee D-9, 422.

Electrical Insulating Materials. Report of Sectional Committee C59, 457.

Investigation of Test Procedures for Dielectric Strength of Liquid Insulation. Report of Committee D-9, Appendix II, 439.

Plastics. Report of Committee D-20, 505.

Proposed Methods of Test for Gas Content of Insulating Oil. Report of Committee D-9, Appendix III, 450.

Summary of Proceedings of the Cincinnati Spring Meeting—Symposium on the Applications of Synthetic Rubbers, 1095.

Electrical-Resistance and Heating Alloys.

Electrical-Heating, Electrical-Resistance and Electric-Furnace Alloys. Report of Committee B-4, 240.

Electrodeposited Coatings.

Corrosion of Iron and Steel. Report of Committee A-5, 87.

Electrodeposited Metallic Coatings. Report of Committee B-8, 278.

Performance Tests, atmospheric exposure tests of electroplated lead coatings on steel. Report of Subcommittee II, Committee B-8, 280.

Report on Inspections of Metallic Coatings on Hardware, etc. Report of Subcommittee VIII, Committee A-5, 96.

Electrolytic Corrosion.

Corrosion of Non-Ferrous Metals and Alloys. Report of Committee B-3, 222.

Electronic Materials.

Electrical-Heating, Electrical-Resistance and Electric-Furnace Alloys. Report of Committee B-4, 240.

Elevated Temperature.

See **Temperature, Effect of.**

Emulsified Asphalts.

See **Asphalts.**

Endurance Testing.

See **Fatigue Testing.**

Engineer.

The Art of Being a Materials Engineer. Annual Address by the President, Dean Harvey, 30.

Entrained Air.

See **Air Entrainment.**

Etching.

See **Grain Size.**

Executive Committee.

Annual Report of the Executive Committee, 39.

Exposure Tests.

See **Corrosion; Weathering.**

F

Fabrics.

See **Textile Materials.**

Fading.

Measurement of Fading Resistance of Camouflage Type Finishes by Accelerated Weathering—J. W. Iliff and L. B. Darrall, 905.

Fatigue Testing.

Fatigue of Metals. Report of the Research Committee, 136.
Fatigue Tests on Compressed and Impregnated Laminated Wood—Albert G. H. Dietz and Henry Grinsfelder. Published in ASTM BULLETIN, No. 129, August, 1944, p. 31. Discussion, 34.
Third Progress Report on the Effect of Size of Specimen on Fatigue Strength of Three Types of Steel—D. Morkovin and H. F. Moore. Report of Research Committee on Fatigue of Metals, Appendix, 137. Discussion, 156.

Fiberboard.

Paper and Paper Products. Report of Committee D-6, 411.

Fibers.

Textile Fibers—An Engineering Approach to Their Properties and Utilization. Nineteenth Edgar Marburg Lecture—Harold DeWitt Smith, 543.
Textile Materials. Report of Committee D-13, 474.

Filler Metal.

Filler Metal. Report of Joint Committee, 216.

Filters.

Symposium on Analytical Colorimetry and Photometry:
  Opening Remarks—G. E. F. Lundell, 709.
  Introduction—Trends in Analytical Chemistry—B. L. Clarke, 710.
  Colorimetric Analysis and Beer's Law—John L. Hague, 712.
  Filter Photometers—A. E. Ruehle, 718.
  Glass Photometric Filters—O. A. Gage, 720.
  Spectrophotometers—Kasson S. Gibson, 725.
  The Chemistry in Colorimetry—M. G. Mellon, 733.
  Bibliography of Photoelectric Spectrophotometric Methods of Analysis for Inorganic Ions—J. W. Stillman, 740.
  Colorimetric Determination of Silicon in Aluminum Alloys—Joseph J. Stumm, 749.
  Colorimetric Methods for the Analysis of Magnesium-Base Alloys—V. A. Stenger, 754.
  Colorimetric Methods for the Analysis of Copper-Base Alloys and Refined Lead—C. Zischkau, 762.
  Colorimetric Methods for the Analysis of Ferrous Alloys—Arba Thomas, 769.

Finances.

Annual Report of the Executive Committee, 39.
Effect of Temperature on the Properties of Metals. Report of Joint Research Committee, 159.

Fineness.

Comparative Tests of 52 Brands of Portland Cement from 15 Countries—Eugene V. Barrett, 793. Discussion, 802.

Fire Brick.

See **Refractories.**

Flow.

Flow of Thermosetting Plastics at Elevated Temperatures—J. Delmonte and E. Watkins, 1009. Discussion, 1016.

Fly Ash.

Application of Fly Ash for Lean Concrete Mixes—Harry A. Frederick, 810. Discussion, 819.

Footwear.

Summary of Proceedings of the Cincinnati Spring Meeting—Symposium on the Applications of Synthetic Rubbers, 1095.

Fuel Oil.

See **Petroleum Products.**

G

Galvanic Corrosion.

Corrosion of Non-Ferrous Metals and Alloys. Report of Committee B-3, 222.

Galvanizing.

See **Zinc Coatings.**

Gas Content Test.

Proposed Methods of Test for Gas Content of Insulating Oil. Report of Committee D-9, Appendix III, 450.

Gas Welding.

See **Welds.**

Gaseous Fuels.

Gaseous Fuels. Report of Committee D-3, 399.

Gasoline.

Petroleum Products and Lubricants. Report of Committee D-2, 368.

Proposed Method of Test for Potential Gum in Aviation Gasoline. Report of Committee D-2, Appendix IV, 393.

Glass.

Electrical Insulating Materials. Report of Committee D-9, 422.

Glass and Glass Products. Report of Committee C-14, 354.

Glass Textiles.

See also **Textiles.**

Recommendations Affecting Standards for Textile Materials. Report of Committee D-13, Appendix, 481.

Textile Materials. Report of Committee D-13, 474.

Grain Size.

Metallography. Report of Committee E-4, 523.

A Numerical Rating Method for the Routine Metallographic Examination of Commercial Magnesium Alloys—P. F. George. Published in ASTM BULLETIN, No. 129, August, 1944, p. 35. Discussion, p. 43.

Study of Effects of Variables on the Creep Resistance of Steels (Project No. 18)—H. C. Cross and W. Simmons. Report of Joint Research Committee on Effect of Temperature on the Properties of Metals, Appendix I, 161.

Gray Iron.

See **Cast Iron.**

Grease.

See **Lubricants.**

Gum Test.

Proposed Method of Test for Potential Gum in Aviation Gasoline. Report of Committee D-2, Appendix IV, 393.

H

Hard Rubber.

See **Rubber Products.**

Hardness Testing.

Factors Affecting Hardness Relationships in the Range 50 to 250 Brinell—Robert H. Heyer, 1027. Discussion, 1046.

Indentation Hardness of Plastics—Ladislav Boor, 969. Discussion, 992.
Methods of Testing. Report of Committee E-1, 515.

Hardware.

Report on Inspections of Metallic Coatings on Hardware, etc. Report of Subcommittee VIII, Committee A-5, 96.

Heating Elements.

See **Electrical-Resistance and Heating Alloys.**

High-Temperature Service Materials.

See **Refractories; Temperature, Effect of.**

High-Temperature Testing.

See **Temperature, Effect of.**

Hose.

Summary of Proceedings of the Cincinnati Spring Meeting—Symposium on the Applications of Synthetic Rubbers, 1095.

I

Immersion Test.

An Alternate Immersion Test for Aluminum-Copper Alloys—R. B. Mears, C. J. Walton, and G. G. Eldredge, 639.
Corrosion of Non-Ferrous Metals and Alloys. Report of Committee B-3, 222.

Impact Testing.

Impact Testing of Plastics—II. Factors Which Influence the Energy Absorbed by the Specimen—David Telfair and H. K. Nason, 993. Discussion, 1006.

Indentation Hardness.

See **Hardness Testing.**

Industrial Aromatic Hydrocarbons.

Industrial Aromatic Hydrocarbons. Report of Committee D-16, 490.

Industrial Waters.

See **Water.**

Insulating Materials.

See **Electrical Insulating Materials; Refractories; Thermal Insulating Materials.**

Iron.

See also **Cast Iron; Malleable Iron; Wrought Iron.**
Colorimetric Methods for the Analysis of Ferrous Alloys—Arba Thomas, 769.
Corrosion of Iron and Steel. Report of Committee A-5, 87.
Factors Affecting Hardness Relationships in the Range 50 to 250 Brinell—Robert H. Heyer, 1027. Discussion, 1046.
Filler Metal. Report of Joint Committee, 216.
Magnetic Properties. Report of Committee A-6, 114.
Summary of Proceedings of Round-Table Discussion on Centrifugal Castings—N. L. Mochel, 779.

Iron-Chromium-Nickel Alloys.

See **Corrosion-Resisting Alloy Steels; Electrical-Resistance and Heating Alloys.**

Izod Impact.

See **Impact Testing.**

L

Laboratory Technician.

The Art of Being a Materials Engineer. Annual Address by the President, Dean Harvey, 30.

Lacquers.

See also **Electrical Insulating Materials.**
Paint, Varnish, Lacquer, and Related Products. Report of Committee D-1, 362.

Laminated Wood.

Fatigue Tests on Compressed and Impregnated Laminated Wood—Albert G. H. Dietz and Henry Grinsfelder. Published in ASTM BULLETIN, No. 129, August, 1944, p. 31. Discussion, 34.

Latex.

See **Rubber Products.**

Lead.

Atmospheric Corrosion. Report of Subcommittee VI, Committee B-3, 224.
Colorimetric Methods for the Analysis of Copper-Base Alloys and Refined Lead—C. Zischkau, 762.
Non-Ferrous Metals and Alloys. Report of Committee B-2, 220.
Performance Tests, atmospheric exposure tests of electroplated lead coatings on steel. Report of Subcommittee II, Committee B-8, 280.
Proposed Specifications for Lead-Alloy (Hot-Dip) Coated Steel Sheets. Report of Committee A-5, Appendix, 110.

Lead Coatings.

Report on Inspections of Metallic Coatings on Hardware, etc. Report of Subcommittee VIII, Committee A-5, 96.

Lecture.

Textile Fibers—An Engineering Approach to Their Properties and Utilization. Nineteenth Edgar Marburg Lecture—Harold DeWitt Smith, 543.

Light Aging Test.

See **Weathering.**

Light Metals.

See **Aluminum; Magnesium.**

Lime.

The Effects of Certain Variations in Consistency and Curing Conditions on the Compressive Strengths of Cement-Lime Mortars—G. J. Fink, 780. Discussion, 788.
Lime. Report of Committee C-7, 317.
Use of the Autoclave for Testing Lime. Report of Special Subcommittee, Committee C-7, 320.

Liquid Dielectrics.

See **Askarels; Electrical Insulating Materials; Transformer Oils.**

Low-Temperature Testing.

See **Temperature, Effect of.**

Lubricants.

See also **Petroleum Products.**
Conversion Tables for Petroleum Oils of Metric Tons in Vacuo to Long and Short Tons in Air. Report of Committee D-2, Appendix I, 381.
Oil Measurement. Report of Committee D-2, Appendix II, 384.
Petroleum Products and Lubricants. Report of Committee D-2, 368.
Petroleum Products and Lubricants. Report of Sectional Committee Z11, 398.

M

Magnesium.

Colorimetric Methods for the Analysis of Magnesium-Base Alloys—V. A. Stenger, 754.
Die-Cast Metals and Alloys. Report of Committee B-6, 261.
Factors Affecting Hardness Relationships in the Range 50 to 250 Brinell—Robert H. Heyer, 1027. Discussion, 1046.
Light Metals and Alloys, Cast and Wrought. Report of Committee B-7, 266.
A Numerical Rating Method for the Routine Metallographic Examination of Commercial Magnesium Alloys—P. F. George. Published in ASTM BULLETIN, No. 129, August, 1944, p. 35. Discussion, p. 43.
Proposed Revisions in Tentative Methods of Preparation of Metallographic Specimens Report of Committee E-4, Appendix, 525
Recommendations Affecting Standards for Light Metals and Alloys, Cast and Wrought. Report of Committee B-7, Appendix, 270.
The Technical Cohesive Strength of Some Steels and Light Alloys at Low Temperatures—D. J. McAdam, Jr., R. W. Mebs, and G. W. Geil, 593. Discussion 624.

Magnesium Sulfate Test.

A Comparison of Results of Sieving Procedures in Soundness Tests on Maine Sands—Andrew Adams and Horace A. Pratt, 806.

Magnetic Testing.

Magnetic Properties. Report of Committee A-6, 114.
Report on Round-Robin Core Loss Testing at High Flux Densities. Committee A-6 120.

Malleable Iron.

Malleable-Iron Castings. Report of Committee A-7, 124.

Marburg Lecture.

Textile Fibers—An Engineering Approach to Their Properties and Utilization. Nineteenth Edgar Marburg Lecture—Harold DeWitt Smith, 543.

Masonry Units.

See also **Brick.**
Manufactured Masonry Units. Report of Committee C-15, 356.
Mortars for Unit Masonry. Report of Committee C-12, 352.

Materials Engineer.

The Art of Being a Materials Engineer. Annual Address by the President, Dean Harvey, 30.

Melton.

Factors Influencing the Breaking Strength of Army and Navy Fabrics—Werner von Bergen, John C. Hintermaier, and Eric Ullman, 916.

Membership.

Annual Report of the Executive Committee, 39.

Metal Powders.

Metal Powders and Metal Powder Products. Report of Committee B-9, 292.

Metallography.

Metallography. Report of Committee E-4 523.
A Numerical Rating Method for the Routine Metallographic Examination of Commercial Magnesium Alloys—P. F. George. Published in ASTM BULLETIN, No. 129, August, 1944, p. 35. Discussion, p. 43.
Proposed Revisions in Tentative Methods of Preparation of Metallographic Specimens. Report of Committee E-4, Appendix, 525.

Methods of Testing.

(Papers and reports covering methods of analysis, sampling, testing, etc., are indexed under the materials and subjects covered by them.)
Methods of Testing. Report of Committee E-1, 515.

Mica.

Electrical Insulating Materials. Report of Committee D-9, 422.

Micro-Deformation.

Micro-Deformation Under Tension and Compression Loads of Thin Aluminum Alloy Sheets for Aircraft Construction—Georges Welter, 665. Discussion 682.

Modulus of Elasticity.

The Effect of Discontinuities on the Natural Frequency of Beams—Philip G. Kirmser, 897.
Tests Comparing the Modulus of Elasticity of Portland Cement Concrete as Determined by the Dynamic (Sonic) and Compression (Secant at 1000 psi.) Methods—Thomas E. Stanton. Published in ASTM BULLETIN, No. 131, December, 1944, p. 17. Discussion, p. 20.

Molded Insulating Materials.

See **Electrical Insulating Materials; Plastics; Thermal Insulating Materials.**

Mortar.

The Data on Darex AEA—summarized by H. J. Gilkey. Report of Committee C-1, Appendix, 300.
The Effects of Certain Variations in Consistency and Curing Conditions on the Compressive Strengths of Cement-Lime Mortars—G. J. Fink, 780. Discussion, 788.
Lime. Report of Committee C-7, 317.
Mortars for Unit Masonry. Report of Committee C-12, 352.
Report of Working Committee on Additions. Report of Committee C-1, 299.

Mortar (*Continued*).

Report on Cooperative Studies of Proposed Method of Test for Air Content of Portland-Cement Mortar. Report of Committee C-1, Appendix I, 306.
Use of the Autoclave for Testing Lime. Report of Special Subcommittee, Committee C-7, 320.
Volumetric Method for Determining the Air Content of Freshly Mixed Concrete—J. C. Pearson. Report of Committee C-9, Appendix, 343. Discussion, 351.

Motor Fuel.

See **Gasoline; Petroleum Products.**

Motor Oils.

See **Lubricants; Petroleum Products.**

N

Nails.

Report on Inspections of Metallic Coatings on Hardware, etc. Report of Subcommittee VIII, Committee A-5, 96.

Natural Building Stone.

See **Aggregates.**

Natural Frequency.

The Effect of Discontinuities on the Natural Frequency of Beams—Philip G. Kirmser, 897.

Naval Stores.

Naval Stores. Report of Committee D-17, 492.
Proposed Methods of Test for Unsaponifiable Matter in Rosin. Report of Committee D-17, Appendix, 495.

Nickel.

Atmospheric Corrosion. Report of Subcommittee VI, Committee B-3, 224.
Electrodeposited Metallic Coatings. Report of Committee B-8, 278.
Non-Ferrous Metals and Alloys. Report of Committee B-2, 220.

Nickel-Chromium Alloys.

See **Alloy Steel; Corrosion-Resisting Alloy Steel; Electrical Resistance and Heating Alloys.**

Nickel-Copper Alloys.

Atmospheric Corrosion. Report of Subcommittee VI, Committee B-3, 224.
Non-Ferrous Metals and Alloys. Report of Committee B-2, 220.

Nickel-Silver Alloy.

See **Brass; Bronze.**

Nomenclature.

See **Definitions of Terms.**

Notched Specimen.

The Technical Cohesive Strength of Some Steels and Light Alloys at Low Temperatures—D. J. McAdam, Jr., R. W. Mebs, and G. W. Geil, 593. Discussion 624.

Numerical Rating Method.

A Numerical Rating Method for the Routine Metallographic Examination of Commercial Magnesium Alloys—P. F. George. Published in ASTM BULLETIN, No. 129, August, 1944, p. 35. Discussion, p. 43.

O

Oils.

See **Lubricants; Petroleum Products; Transformer Oils.**

Oxidation Test.

Proposed Method of Test for Potential Gum in Aviation Gasoline. Report of Committee D-2, Appendix IV, 393.

P

Paints.

See also **Electrical Insulating Materials.**
The Interpretation of Visual Rusting Standards—W. F. Singleton, 910.
Measurement of Fading Resistance of Camouflage Type Finishes by Accelerated Weathering—J. W. Iliff and L. B. Darrall, 905.
Paint, Varnish, Lacquer, and Related Products. Report of Committee D-1, 362.

Paper.

Electrical Insulating Materials. Report of Committee D-9, 422.

Paper and Paper Products. Report of Committee D-6, 411.
The Use of Selected Waters in Pulp and Paper Manufacture—Lewis B. Miller, 1061.

Papers and Publications.

Annual Report of the Executive Committee, 39.
Summary of Proceedings of the Forty-seventh Annual Meeting, 1.

Parkerized Coatings.

Report on Inspections of Metallic Coatings on Hardware, etc. Report of Subcommittee VIII, Committee A-5, 96.

Particle Size.

Methods of Testing. Report of Committee E-1, 515.

Paving Materials.

See **Aggregates; Asphalt; Brick; Cement; Concrete; Soils.**

Penetration.

See **Consistency.**

Permeability.

See **Magnetic Testing.**

Petroleum Products.

Conversion Tables for Petroleum Oils of Metric Tons in Vacuo to Long and Short Tons in Air. Report of Committee D-2, Appendix I, 381.
Investigation of Test Procedures for Dielectric Strength of Liquid Insulation. Report of Committee D-9, Appendix II, 439.
Oil Measurement. Report of Committee D-2, Appendix II, 384.
Petroleum Products and Lubricants. Report of Committee D-2, 368.
Petroleum Products and Lubricants. Report of Sectional Committee Z11, 398.
Proposed Method of Analysis of Petroleum Sulfonates. Report of Committee D-2, Appendix III, 386.
Proposed Method of Test for Potential Gum in Aviation Gasoline. Report of Committee D-2, Appendix IV, 393.
Proposed Methods of Test for Gas Content of Insulating Oil. Report of Committee D-9, Appendix III, 450.

pH Value.

Methods of Testing. Report of Committee E-1, 515.

Phenolic Materials.

See **Electrical Insulating Materials; Plastics.**

Photometry.

Symposium on Analytical Colorimetry and Photometry:
  Opening Remarks—G. E. F. Lundell, 709.
  Introduction—Trends in Analytical Chemistry—B. L. Clark, 710.
  Colorimetric Analysis and Beer's Law—John L. Hague, 712.
  Filter Photometers—A. E. Ruehle, 718.
  Glass Photometric Filters—O. A. Gage, 720.
  Spectrophotometers—Kasson S. Gibson, 725.
  The Chemistry in Colorimetry—M. G. Mellon, 733.
  Bibliography of Photoelectric Spectrophotometric Methods of Analysis for Inorganic Ions—J. W. Stillman, 740.
  Colorimetric Determination of Silicon in Aluminum Alloys—Joseph J. Stumm, 749.
  Colorimetric Methods for the Analysis of Magnesium-Base Alloys—V. A. Stenger, 754.
  Colorimetric Methods for the Analysis of Copper-Base Alloys and Refined Lead—C. Zischkau, 762.
  Colorimetric Methods for the Analysis of Ferrous Alloys—Arba Thomas, 769.

Pigments.

See also **Paints.**
Paint, Varnish, Lacquer, and Related Products. Report of Committee D-1, 362.

Pine Oil.

Naval Stores. Report of Committee D-17, 492.

Pipe.

Summary of Proceedings of Round-Table Discussion on Centrifugal Castings, N. L. Mochel, 779.

Plastic Refractories.

See **Refractories.**

Plastics.

See also **Electrical Insulating Materials.**
Electrical Insulating Materials. Report of Committee D-9, 422.
Flow of Thermosetting Plastics at Elevated Temperatures—J. Delmonte and E. Watkins, 1009. Discussion, 1016.
Impact Testing of Plastics—II. Factors Which Influence the Energy Absorbed by the Specimen—David Telfair and H. K. Nason, 993. Discussion, 1006.
Indentation Hardness of Plastics—Ladislav Boor, 969. Discussion, 992.
Plastics. Report of Committee D-20, 505.
Proposed Revisions in Standards for Plastics. Report of Committee D-20, Appendix, 510.
Short-Time Static Tests and Creep Tests of a Paper Laminated Plastic—W. N. Findley and W. J. Worley, 949. Discussion, 967.

Plating.

See **Electrodeposited Coatings.**

Plywood.

Timber. Report of Committee D-7, 415.

Portland Cement.

See **Cement.**

Powder Metal Products.

See **Metal Powders.**

Presidential Address.

The Art of Being a Materials Engineer. Annual Address by the President, Dean Harvey, 30.

Processing Rubber.

Summary of Proceedings of the Cincinnati Spring Meeting—Symposium on the Applications of Synthetic Rubbers, 1095.

Publications.

See **Papers and Publications.**

Pull-Out Strength.

The Measurement of Concrete Strength by Embedded Pull-Out Bars—Bailey Tremper, 880.

Pulp.

The Use of Selected Waters in Pulp and Paper Manufacture—Lewis B. Miller, 1061.

Q

Quicklime.

See **Lime.**

R

Radio Materials.

See **Electrical-Resistance and Heating Alloys; Electronic Materials.**

Rate of Strain.

See **Speed of Testing.**

Rate of Stressing.

See **Speed of Testing.**

Rayon.

See also **Textiles.**
Recommendations Affecting Standards for Textile Materials. Report of Committee D-13, Appendix, 481.
Textile Materials. Report of Committee D-13, 474.

Reflectance.

Measurement of Fading Resistance of Camouflage Type Finishes by Accelerated Weathering—J. W. Iliff and L. B. Darrall, 905.

Refractories.

Refractories. Report of Committee C-8, 331.

Research.

Annual Report of the Executive Committee, 39.
The Art of Being a Materials Engineer. Annual Address by the President, Dean Harvey, 30.

Correlation of Short- and Long-Time Elevated Temperature Test Methods (Project No. 25). Report of Joint Research Committee on Effect of Temperature on the Properties of Metals, Appendix II, 186.

Effect of Temperature on the Properties of Metals. Report of Joint Research Committee, 159.

Fatigue of Metals. Report of the Research Committee, 136.

Study of Effects of Variables on the Creep Resistance of Steels (Project No. 18)—H. C. Cross and W. Simmons. Report of Joint Research Committee on Effect of Temperature on the Properties of Metals, Appendix I, 161.

Third Progress Report on the Effect of Size of Specimen on Fatigue Strength of Three Types of Steel—D. Morkovin and H. F. Moore. Report of Research Committee on Fatigue of Metals, Appendix, 137. Discussion, 156.

Resins.

See also **Plastics; Rosin; Shellac; Soaps and Detergents; Varnish.**

Fatigue Tests on Compressed and Impregnated Laminated Wood—Albert G. H. Dietz and Henry Grinsfelder. Published in ASTM BULLETIN, No. 129, August, 1944, p. 31. Discussion, 34.

The Reaction of Vinsol Resin as It Affects the Air Entrainment of Portland-Cement Concrete—Charles E. Wuerpel and Albert Weiner. Published in ASTM BULLETIN, No. 130, October, 1944, p. 41. Discussion, p. 43.

Road Materials.

See also **Aggregates, Asphalt; Brick; Cement, Concrete; Soils.**

Road and Paving Materials. Report of Committee D-4, 401.

Soils for Engineering Purposes. Report of Committee D-18, 497.

Rockwell Hardness.

See **Hardness Testing.**

Roofing.

Bituminous Waterproofing and Roofing Materials Report of Committee D-8, 417.

Rosin.

Naval Stores. Report of Committee D-17, 492.

Proposed Method of Test for Unsaponifiable Matter in Rosin. Report of Committee D-17, Appendix, 495.

Rubber Products.

Rubber Products. Report of Committee D-11, 459.

Summary of Proceedings of the Cincinnati Spring Meeting—Symposium on the Applications of Synthetic Rubbers, 1095.

Rusting Standards.

The Interpretation of Visual Rusting Standards—W. F. Singleton, 910.

S

Salt Spray Tests.

See also **Corrosion.**

Basic Requirements in the Standardization of the Salt Spray Corrosion Test—Leo J. Waldron, 654. Discussion, 663.

Corrosion of Non-Ferrous Metals and Alloys, Report of Committee B-3, 222.

Sampling.

Oil Measurement. Report of Committee D-2, Appendix II, 384.

Sand.

A Comparison of Results of Sieving Procedures in Soundness Tests on Maine Sands—Andrew Adams and Horace A. Pratt, 806.

Sand Castings.

See **Castings.**

Sanford E. Thompson Award.

Summary of Proceedings of the Forty-seventh Annual Meeting, 26. Report of Committee C-9, 336.

Screws.

Report on Inspections of Metallic Coatings on Hardware, etc. Report of Subcommittee VIII, Committee A-5, 96.

Sea Water Corrosion.

See **Corrosion; Immersion Tests.**

Serge.

Factors Influencing the Breaking Strength of Army and Navy Fabrics—Werner von Bergen, John C. Hintermaier, and Eric Ullman, 916.

Shear Testing.

Short-Time Tests of Solders and Soldered Joints—J. A. Kies and W. F. Roeser, 691. Discussion, 707.

Sheets.

Proposed Specifications for Lead-Alloy (Hot-Dip) Coated Steel Sheets. Report of Committee A-5, Appendix, 110.

Shellac.

Electrical Insulating Materials. Report of Committee D-9, 422.

Paint, Varnish, Lacquer, and Related Products. Report of Committee D-1, 362.

Sherardized Coatings.

Report on Inspections of Metallic Coatings on Hardware, etc. Report of Subcommittee VIII, Committee A-5, 96.

Shingles.

Bituminous Waterproofing and Roofing Materials. Report of Committee D-8, 417.

Shipping Containers.

Paper and Paper Products. Report of Committee D-6, 411.

Sieving.

A Comparison of Results of Sieving Procedures in Soundness Tests on Maine Sands—Andrew Adams and Horace A. Pratt, 806.

Silicon.

Colorimetric Determination of Silicon in Aluminum Alloys—Joseph J. Stumm, p. 749.

Silicon Steel.

Report on Round-Robin Core Loss Testing at High Flux Densities. Committee A-6, 120.

Size Effect.

Third Progress Report on the Effect of Size of Specimen on Fatigue Strength of Three Types of Steel—D. Morkovin and H. F. Moore. Report of Research Committee on Fatigue of Metals, Appendix, 137. Discussion, 156.

Soaps and Detergents.

Soaps and Detergents. Report of Committee D-12, 470.

Soils.

Soils for Engineering Purposes. Report of Committee D-18, 497.

Solder.

Non-Ferrous Metals and Alloys. Report of Committee B-2, 220.

Short-Time Tests of Solders and Soldered Joints—J. A. Kies and W. F. Roeser, 691. Discussion, 707.

Sonic Testing.

See **Dynamic Testing.**

Soundness.

A Comparison of Results of Sieving Procedures in Soundness Tests on Maine Sands—Andrew Adams and Horace A. Pratt, 806.

Specimens.

See **Test Specimens.**

Spectrographic Analysis.

Quantitative Spectrographic Analysis of Copper Alloys—R. A. Wolfe and Emile J. Jemal. Published in ASTM BULLETIN, No. 129, August, 1944, p. 45. Discussion, p. 52.

Spectrographic Analysis. Report of Committee E-2, 519.

Symposium on Analytical Colorimetry and Photometry:
  - Opening Remarks—G. E. F. Lundell, 709.
  - Introduction—Trends in Analytical Chemistry—B. L. Clarke, 710.
  - Colorimetric Analysis and Beer's Law—John L. Hague, 712.

Filter Photometers—A. E. Ruehle, 718.
Glass Photometric Filters—O. A. Gage, 720.
Spectrophotometers—Kasson S. Gibson, 725.
The Chemistry in Colorimetry—M. G. Mellon, 733.
Bibliography of Photoelectric Spectrophotometric Methods of Analysis for Inorganic Ions—J. W. Stillman, 740.
Colorimetric Determination of Silicon in Aluminum Alloys—Joseph J. Stumm, 749.
Colorimetric Methods for the Analysis of Magnesium-Base Alloys—V. A. Stenger, 754.
Colorimetric Methods for the Analysis of Copper-Base Alloys and Refined Lead—C. Zischkau, 762.
Colorimetric Methods for the Analysis of Ferrous Alloys—Arba Thomas, 769.

Speed of Testing.

Cooperative Study of Effect of Rate of Strain on Tensile Properties of Stainless Sheets. Report of Subcommittee V, Committee A-10, Appendix, 133.
Correlation of Short- and Long-Time Elevated Temperature Test Methods (Project No. 25). Report of Joint Research Committee on Effect of Temperature on the Properties of Metals, Appendix II, 186.
Impact Testing of Plastics—II. Factors Which Influence the Energy Absorbed by the Specimen—David Telfair and H. K. Nason, 993. Discussion, 1006.
Methods of Testing. Report of Committee E-1, 515.

Sponge Rubber.

See **Rubber Products.**

Spreading Test.

Short-Time Tests of Solders and Soldered Joints—J. A. Kies and W. F. Roeser, 691. Discussion, 707.

Stainless Steel.

See **Alloy Steel; Corrosion-Resisting Steel.**

Standardization.

Annual Report of the Executive Committee, 39.
The Art of Being a Materials Engineer. Annual Address by the President, Dean Harvey, 30.
Standards. Report of Committee E-10, 533.
Summary of Proceedings of the Forty-seventh Annual Meeting, 1.

Static Tests.

Short-Time Static Tests and Creep Tests of a Paper Laminated Plastic—W. N. Findley and W. J. Worley, 949. Discussion, 967.

Statistical Analysis.

Atmospheric Corrosion. Report of Subcommittee VI, Committee B-3, 224.
Methods of Testing. Report of Committee E-1, 515.

Steel.

Chemical Analysis of Metals. Report of Committee E-3, 521.
Colorimetric Methods for the Analysis of Ferrous Alloys—Arba Thomas, 769.
Cooperative Study of Effect of Rate of Strain on Tensile Properties of Stainless Sheets. Report of Subcommittee V, Committee A-10, Appendix, 133.
Correlation of Short- and Long-Time Elevated Temperature Test Methods (Project No. 25). Report of Joint Research Committee on Effect of Temperature on the Properties of Metals, Appendix, II, 186.
Corrosion of Iron and Steel. Report of Committee A-5, 87.
Effect of Temperature on the Properties of Metals. Report of Joint Research Committee, 159.
Factors Affecting Hardness Relationships in the Range 50 to 250 Brinell—Robert H. Heyer, 1027. Discussion, 1046.
Fatigue of Metals. Report of the Research Committee, 136.
Field Tests of Metallic Coatings. Report of Subcommittee VIII, Committee A-5, 92.
Filler Metal. Report of Joint Committee, 216.
The Interpretation of Visual Rusting Standards—W. F. Singleton, 910.
Iron-Chromium, Iron-Chromium-Nickel and Related Alloys. Report of Committee A-10, 126.

Steel (*Continued*).
- Magnetic Properties. Report of Committee A-6, 114.
- Metallography. Report of Committee E-4, 523.
- Performance Tests, atmospheric exposure tests of electroplated lead coatings on steel. Report of Subcommittee II, Committee B-8, 280.
- Proposed Revisions in Standards for Steel. Report of Committee A-1, Appendix, 73.
- Proposed Revisions in Tentative Methods of Preparation of Metallographic Specimens. Report of Committee E-4, Appendix, 525.
- Proposed Specifications for Lead-Alloy (Hot-Dip) Coated Steel Sheets. Report of Committee A-5, Appendix, 110.
- Record of failures in atmospheric tests at Annapolis of No. 22-gage copper-bearing and non-copper-bearing corrugated black sheets, Report of Committee A-5, 89.
- Report on Inspections of Metallic Coatings on Hardware, etc. Report of Subcommittee VIII, Committee A-5, 96.
- Report on Round-Robin Core Loss Testing at High Flux Densities. Committee A-6, 120.
- Short-Time Tests of Solders and Soldered Joints—J. A. Kies and W. F. Roeser, 691. Discussion, 707.
- Steel. Report of Committee A-1, 63.
- Study of Effects of Variables on the Creep Resistance of Steels (Project No. 18)—H. C. Cross and W. Simmons. Report of Joint Research Committee on Effect of Temperature on the Properties of Metals, Appendix I, 161.
- Summary of Proceedings of Round-Table Discussion on Centrifugal Castings—N. L. Mochel, 779.
- The Technical Cohesive Strength of Some Steels and Light Alloys at Low Temperatures—D. J. McAdam, Jr., R. W. Mebs, and G. W. Geil, 593. Discussion, 624.
- Third Progress Report on the Effect of Size of Specimen on Fatigue Strength of Three Types of Steel—D. Morkovin and H. F. Moore. Report of Research Committee on Fatigue of Metals, Appendix, 137. Discussion, 156.

Stone.
- See **Aggregates.**

Strain Gage.
- Characteristics of the Tuckerman Strain Gage—Bruce L. Wilson, 1017.

Structural Steel.
- See **Steel.**

Sulfonates, Petroleum.
- See also **Soaps and Detergents.**
- Proposed Method of Analysis of Petroleum Sulfonates. Report of Committee D-2, Appendix III, 386.

Summary of Proceedings.
- Summary of Proceedings of the Forty-seventh Annual Meeting, 1.
- Summary of Proceedings of the Cincinnati Spring Meeting—Symposium on the Applications of Synthetic Rubbers, 1095.
- Summary of Proceedings of Round-Table Discussion on Centrifugal Castings—N. L. Mochel, 779.

Sustained Loading.
- Some Properties of Concrete Under Sustained Combined Stresses—C. Martin Duke and Harmer E. Davis, 888.

Symbols.
- See **Nomenclature.**

Synthetic Detergents.
- See **Soaps and Detergents.**

Synthetic Rubber.
- Rubber Products. Report of Committee D-11, 459.
- Summary of Proceedings of the Cincinnati Spring Meeting—Symposium on the Applications of Synthetic Rubbers, 1095.

T

Tall Oil.
- Naval Stores. Report of Committee D-17, 492.

Tar.
- See **Road Materials; Waterproofing Materials.**

Temperature, Effect of

Correlation of Short- and Long-Time Elevated Temperature Test Methods (Project No. 25). Report of Joint Research Committee on Effect of Temperature on the Properties of Metals, Appendix, II, 186.
Effect of Temperature on the Properties of Metals. Report of Joint Research Committee, 159.
Electrical-Heating, Electrical-Resistance and Electric-Furnace Alloys. Report of Committee B-4, 240.
Flow of Thermosetting Plastics at Elevated Temperatures—J. Delmonte and E. Watkins, 1009. Discussion, 1016.
Study of Effects of Variables on the Creep Resistance of Steels (Project No. 18)—H. C. Cross and W. Simmons. Report of Joint Research Committee on Effect of Temperature on the Properties of Metals, Appendix, I, 161.
The Technical Cohesive Strength of Some Steels and Light Alloys at Low Temperatures—D. J. McAdam, Jr., R. W. Mebs, and G. W. Geil, 593. Discussion 624.

Tension Testing.

Comparative Tests of 52 Brands of Portland Cement from 15 Countries—Eugene V. Barrett, 793. Discussion, 802.
Correlation of Short- and Long-Time Elevated Temperature Test Methods (Project No. 25). Report of Joint Research Committee on Effect of Temperature on the Properties of Metals, Appendix II, 186.
Factors Affecting Hardness Relationships in the Range 50 to 250 Brinnell—Robert H. Heyer, 1027. Discussion, 1046.
Micro-Deformation Under Tension and Compression Loads of Thin Aluminum Alloy Sheets for Aircraft Construction—Georges Welter, 665. Discussion, 682.
Short-Time Static Tests and Creep Tests of a Paper Laminated Plastic—W. N. Findley and W. J. Worley, 949. Discussion, 967.
Study of Effects of Variables on the Creep Resistance of Steels (Project No. 18)—H. C. Cross and W. Simmons. Report of Joint Research Committee on Effect of Temperature on the Properties of Metals, Appendix I, 161.

Terne Plate.

Performance Tests, atmospheric exposure tests of electroplated coatings on steel. Report of Subcommittee II, Committee B-8, 280.

Test Specimens.

Evolution of Test Specimen for Non-Ferrous Castings—A. J. Smith, 625. Discussion, 636.
Third Progress Report on the Effect of Size of Specimen on Fatigue Strength of Three Types of Steel—D. Morkovin and H. F. Moore. Report of Research Committee on Fatigue of Metals, Appendix, 137. Discussion, 156.

Testing Apparatus.

Methods of Testing. Report of Committee E-1, 515.

Testing, Physical Methods of.

(Papers and reports covering methods of analysis, sampling, testing, etc., are indexed under the materials and subjects covered by them.)

Textiles.

Textile Fibers—An Engineering Approach to Their Properties and Utilization. Nineteenth Edgar Marburg Lecture—Harold DeWitt Smith, 543.
Factors Influencing the Breaking Strength of Army and Navy Fabrics—Werner von Bergen, John C. Hintermaier, and Eric Ullman, 916.
Recommendations Affecting Standards for Textile Materials. Report of Committee D-13, Appendix, 481.
Textile Materials. Report of Committee D-13, 474.

Thermal Insulating Materials.

Thermal Insulating Materials. Report of Committee C-16, 358.

Thermometers.

Methods of Testing. Report of Committee E-1, 515.

Thermosetting and Thermoplastic Materials.

See **Plastics.**

Thermostatic Metals.

Electrical-Heating, Electrical-Resistance and Electric-Furnace Alloys. Report of Committee B-4, 240.

Tile.

Manufactured Masonry Units. Report of Committee C-15, 356.

Timber.

Fatigue Tests on Compressed and Impregnated Laminated Wood—Albert G. H. Dietz and Henry Grinsfelder. Published in ASTM BULLETIN, No. 129, August, 1944, p. 31. Discussion, 34.

Timber. Report of Committee D-7, 415.

Tin.

Atmospheric Corrosion. Report of Subcommittee VI, Committee B-3, 224.

Performance Tests, atmospheric exposure tests of electroplated coatings on steel. Report of Subcommittee II, Committee B-8, 280.

Toluene.

Industrial Aromatic Hydrocarbons. Report of Committee D-16, 490.

Torsion Testing.

Short-Time Static Tests and Creep Tests of a Paper Laminated Plastic—W. N. Findley and W. J. Worley, 949. Discussion, 967.

Some Properties of Concrete Under Sustained Combined Stresses—C. Martin Duke and Harmer E. Davis, 888

Total Immersion Tests.

See **Immersion Test.**

Transformer Oil.

Electrical Insulating Materials. Report of Committee D-9, 422.

Investigation of Test Procedures for Dielectric Strength of Liquid Insulation Report of Committee D-9, Appendix II, 439.

Proposed Methods of Test for Gas Content of Insulating Oil. Report of Committee D-9, Appendix III, 450.

Triaxial Stress.

Some Properties of Concrete Under Sustained Combined Stresses—C. Martin Duke and Harmer E. Davis, 888.

Tubes.

Report on Inspections of Metallic Coatings on Hardware, etc. Report of Subcommittee VIII, Committee A-5, 96.

Turpentine.

Naval Stores. Report of Committee D-17, 492.

U

Unsaponifiable Matter.

Proposed Method of Test for Unsaponifiable Matter in Rosin. Report of Committee D-17, Appendix, 495.

V

Varnish.

See also **Electrical Insulating Materials.**

Paint, Varnish, Lacquer, and Related Products. Report of Committee D-1, 362.

Veneers.

Fatigue Tests on Compressed and Impregnated Laminated Wood—Albert G. H. Dietz and Henry Grinsfelder. Published in ASTM BULLETIN, No. 129, August, 1944, p. 31. Discussion, 34.

Vickers Hardness.

See **Hardness Testing.**

Vinsol Resin.

The Reaction of Vinsol Resin as It Affects the Air Entrainment of Portland-Cement Concrete—Charles E. Wuerpel and Albert Weiner. Published in ASTM BULLETIN, No. 130, October, 1944, p. 41. Discussion, p. 43.

Report on Cooperative Studies of Proposed Method of Test for Air Content of Portland-Cement Mortar. Report of Committee C-1, Appendix I, 306.

Visual Rusting Standards.

The Interpretation of Visual Rusting Standards—W. F. Singleton, 910.

W

Water.

Boiler Feedwater Studies. Joint Research Committee, 504.
Round-Table Discussion on Organizing the Classification of Industrial Waters:
  Introduction—W. C. Schroeder, 1051.
  Typical Water Analyses for Classification with Reference to Industrial Use—W. D. Collins, 1057.
  The Use of Selected Waters in Pulp and Paper Manufacture—Lewis B. Miller, 1061.
  Treatment of Various Types of Waters for Operating Pressures Above 400 psi.—R. E. Hall, 1069.
  Classification of Feedwater for Boilers Operating Between 100–400 psi.—J. A. Holmes, 1078.
  General Discussion, 1082.
Water for Industrial Uses. Report of Committee D-19, 500.

Waterproofing Materials.

Bituminous Waterproofing and Roofing Materials. Report of Committee D-8, 417.

Weathering.

See also **Corrosion.**
An Alternate Immersion Test for Aluminum-Copper Alloys—R. B. Mears, C. J. Walton, and G. G. Eldredge, 639.
Atmospheric Corrosion. Report of Subcommittee VI, Committee B-3, 224.
Basic Requirements in the Standardization of the Salt Spray Corrosion Test—Leo J. Waldron 654. Discussion, 663.
Corrosion of Non-Ferrous Metals and Alloys, Report of Committee B-3, 222.
Field Tests of Metallic Coatings. Report of Subcommittee VIII, Committee A-5, 92.
Measurement of Fading Resistance of Camouflage Type Finishes by Accelerated Weathering—J. W. Iliff and L. B. Darrall, 905.
Paint, Varnish, Lacquer, and Related Products. Report of Committee D-1, 362.
Record of failures in atmospheric tests at Annapolis of No. 22-gage copper-bearing and non-copper-bearing corrugated black sheets, Report of Committee A-5, 89.
Report on Inspections of Metallic Coatings on Hardware, etc. Report of Subcommittee VIII, Committee A-5, 96.

Weight.

Conversion Tables for Petroleum Oils of Metric Tons in Vacuo to Long and Short Tons in Air. Report of Committee D-2, Appendix I, 381.

Welds.

Filler Metal. Report of Joint Committee, 216.
Study of Effects of Variables on the Creep Resistance of Steels (Project No. 18)—H. C. Cross and W. Simmons. Report of Joint Research Committee on Effect of Temperature on the Properties of Metals, Appendix I, 161.

Wire.

See also **Steel.**
Copper and Copper-Alloy Wires for Electrical Conductors. Report of Committee B-1, 218.
Electrical-Heating, Electrical-Resistance and Electric-Furnace Alloys. Report of Committee B-4, 240.
Field Tests of Metallic Coatings. Report of Subcommittee VIII, Committee A-5, 92.

Wood.

See **Timber.**

Wool.

See also **Textiles.**
Factors Influencing the Breaking Strength of Army and Navy Fabrics—Werner von Bergen, John C. Hintermaier, and Eric Ullman, 916.
Recommendations Affecting Standards for Textile Materials. Report of Committee D-13, Appendix, 481.
Textile Materials. Report of Committee D-13, 474.

Workability.

Application of Fly Ash for Lean Concrete Mixes—Harry A. Frederick, 810. Discussion, 819.

Worsteds.

Factors Influencing the Breaking Strength of Army and Navy Fabrics—Werner von Bergen, John C. Hintermaier, and Eric Ullman, 916.

Wrought Iron.

Field Tests of Metallic Coatings. Report of Subcommittee VIII, Committee A-5, 92.
Magnetic Properties. Report of Committee A-6, 114.
Record of failures in atmospheric tests at Annapolis of No. 22-gage copper-bearing and non-copper-bearing corrugated black sheets, Report of Committee A-5, 89.
Wrought Iron. Report of Committee A-2, 83.

X

X-ray.

Metallography. Report of Committee E-4, 523.

Xylene.

Industrial Aromatic Hydrocarbons. Report of Committee D-16, 490.

Y

Yarns.

See **Textile Materials.**

Yield Strength.

Cooperative Study of Effect of Rate of Strain on Tensile Properties of Stainless Sheets. Report of Subcommittee V, Committee A-10, Appendix, 133.

Z

Zinc.

Atmospheric Corrosion. Report of Subcommittee VI, Committee B-3, 224.
Die-Cast Metals and Alloys. Report of Committee B-6, 261.
Field Tests of Metallic Coatings. Report of Subcommittee VIII, Committee A-5, 92.
Performance Tests, atmospheric exposure tests of electroplated coatings on steel. Report of Subcommittee II, Committee B-8, 280.

Zinc Coatings.

Corrosion of Iron and Steel. Report of Committee A-5, 87.
Field Tests of Metallic Coatings. Report of Subcommittee VIII, Committee A-5, 92.
Report on Inspections of Metallic Coatings on Hardware, etc. Report of Subcommittee VIII, Committee A-5, 96.

AUTHOR INDEX

VOLUME 44

A

Abrams, Duff A.
Discussion, 852.
Discussion published in ASTM Bulletin, No. 130, October, 1944, p. 43.

Adams, Andrew
A Comparison of Results of Sieving Procedures in Soundness Tests on Maine Sands, 806.

Adams, Robert C.
Discussion, 1083.

Anderegg, F. O.
Discussion, 835.

Anderson, R. P.
Report of Committee D-2 on Petroleum Products and Lubricants, 368.
Report of Committee D-16 on Industrial Aromatic Hydrocarbons, 490.

Arnold, S. M.
Discussion, 1047.

B

Ball, H. J.
Report of Committee D-13 on Textile Materials, 474.

Ball, J. M.
The Physical Properties of the Synthetic Rubbers. Summary of Proceedings of the Cincinnati Spring Meeting—Symposium on the Applications of Synthetic Rubbers, 1095.

Ball, L. W.
Discussion published in ASTM Bulletin, No. 129, August, 1944, p. 44.

Barrett, Eugene V.
Comparative Tests of 52 Brands of Portland Cement from 15 Countries, 793. Discussion, 804.

Barton, J. P.
Report on Round-Robin Core Loss Testing at High Flux Densities, Committee A-6, 120.

Bash, F. E.
Report of Committee B-4 on Electrical-Heating, Electrical-Resistance and Electric-Furnace Alloys, 240.

Bates, P. H.
Report of Committee C-1 on Cement, 294.
Discussion, 802.
Discussion published in ASTM Bulletin, No. 130, October, 1944, p. 43.

Betz, L. Drew
Discussion, 1092.

Bigler, H. P.
Report of Committee A-1 on Steel, 63.

Bolton, J. W.
Report of Committee A-3 on Cast Iron, 85.
Report of Joint Research Committee on Effect of Temperature on the Properties of Metals, 159.
Discussion, 638.

Bonsack, Walter
Discussion published in ASTM Bulletin, No. 129, August, 1944, p. 43.

Boor, Ladislav
Indentation Hardness of Plastics, 969. Discussion, 992.

Bowman, J. J.
Report of Committee E-4 on Metallography, 523.

Boyd, T. A.
Report of Committee D-2 on Petroleum Products and Lubricants, 368.
Report on Sectional Committee Z11 on Petroleum Products and Lubricants, 398.

Bright, H. A.
Report of Committee E-3 on Chemical Analysis of Metals, 521.

Bryant, C. B.
Report of Committee A-2 on Wrought Iron, 83.

Burns, Robert.
Report of Committee D-20 on Plastics, 505.

C

Carpenter, Arthur W.
Introduction. Summary of Proceedings of the Cincinnati Spring Meeting—Symposium on the Applications of Synthetic Rubbers, 1095.

Carpenter, Arthur W. (*Continued*).
Report of Committee D-11 on Rubber Products, 459.

Chapman, Cloyd M.
Report of Committee E-8 on Nomenclature and Definitions, 531.

Christie, J. L.
Report of Committee B-2 on Non-Ferrous Metals and Alloys, 220.

Churchill, H. V.
Report of Committee E-2 on Spectrographic Analysis, 519.

Clamer, G. H.
Discussion, 636.

Clarke, B. L.
Introduction—Trends in Analytical Chemistry, 710.

Colburn, D. S.
Discussion, 833, 834.

Collier, Simon.
Report of Committee D-11 on Rubber Products, 459.

Collins, W. D.
Typical Water Analyses for Classification with Reference to Industrial Use, 1057.

Conner, R. M.
Report of Committee D-3 on Gaseous Fuels, 399.

Cooper, L. V.
Physical Testing of Synthetic Rubber Products. Summary of Proceedings of the Cincinnati Spring Meeting—Symposium on the Applications of Synthetic Rubbers, 1095.

Cope, E. T.
Report of Committee C-16 on Thermal Insulating Materials, 358.

Cross, H. C.
Study of Effects of Variables on the Creep Resistance of Steels. Appendix I, Report of Joint Research Committee on Effect of Temperature on the Properties of Metals, 161.

Curtis, H. L.
Report of Sectional Committee C59 on Electrical Insulating Materials, 457.

D

Dalcher, L. M.
Report of Joint Committee on Filler Metal, 216.

Darrall, L. B.
Measurement of Fading Resistance of Camouflage Type Finishes by Accelerated Weathering, 905.

Davis, C. H.
Report of Committee B-5 on Copper and Copper Alloys, Cast and Wrought, 243.

Davis, Harmer E.
Some Properties of Concrete Under Sustained Combined Stresses, 888.

Davis, Myron P.
Report of Committee D-9 on Electrical Insulating Materials, 422.

Day, L. E.
Discussion, 1091.

De France, M. J.
Specifications for Synthetic Rubber Compounds. Summary of Proceedings of the Cincinnati Spring Meeting—Symposium on the Applications of Synthetic Rubbers, 1095.

Delmonte, J.
Flow of Thermosetting Plastics at Elevated Temperatures, 1009. Discussion, 1016.

Deppeler, J. H.
Report of Joint Committee on Filler Metal, 216.

Dietz, Albert G. H.
Fatigue Tests on Compressed and Impregnated Laminated Wood. Published in ASTM BULLETIN, No. 129, August, 1944, p. 31.

Dixon, J. B.
Report of Committee A-5 on Corrosion of Iron and Steel, 87.

Doherty, Walter G.
Discussion, 819.

Douglass, Clemeunt T.
Precision Indices for Compression Tests of Companion Concrete Cylinders, 839. Discussion, 875.

Douglass, L. R.
Report of Committee D-18 on Soils for Engineering Purposes, 497.

Duke, C. Martin
Some Properties of Concrete Under Sustained Combined Stresses, 888.

E

Eldredge, G. G.
An Alternate Immersion Test for Aluminum-Copper Alloys, 639.

Elliott, William S.
Discussion, 819.

Evans, W. A.
Report of Committee D-9 on Electrical Insulating Materials, 422.

F

Fawcett, O. E.
Investigation of Test Procedures for Dielectric Strength of Insulating Fluids. Appendix II, Report of Committee D-9, 439.

Fellows, C. H.
Report of Joint Research Committee on Boiler Feedwater Studies, 504.

Fieldner, A. C.
Report of Committee D-5 on Coal and Coke, 406.

Findley, W. N.
Short-Time Static Tests and Creep Tests of a Paper Laminated Plastic, 949. Discussion, 968.
Discussion, 1006.

Fink, G. J.
The Effects of Certain Variations in Consistency and Curing Conditions on the Compressive Strengths of Cement-Lime Mortars, 780. Discussion, 791.
Report of Special Subcommittee on Use of the Autoclave for Testing Lime, Committee C-7 on Lime, 320.

Fisher, Harry L.
The Origin and Development of Synthetic Rubbers. Summary of Proceedings of the Cincinnati Spring Meeting—Symposium on the Applications of Synthetic Rubbers, 1095.

Foote, J. H.
Report of Committee B-1 on Copper and Copper Alloy Wires for Electrical Conductors, 218.

Forrest, C. N.
Report of Committee D-4 on Road and Paving Materials, 401.

Foster, Alexander, Jr.
Discussion published in ASTM BULLETIN, No. 130, October, 1944, p. 43.

Frederick, Harry A.
Application of Fly Ash for Lean Concrete Mixes, 810. Discussion, 819, 820.

Fulweiler, W. H.
Report of Committee E-1 on Methods of Testing, 515.

G

Gage, O. A.
Glass Photometric Filters, 720.

Gauger, A. W.
Report of Committee D-3 on Gaseous Fuels, 399.

Geil, G. W.
The Technical Cohesive Strength of Some Steels and Light Alloys at Low Temperatures, 593.

George, P. F.
A Numerical Rating Method for the Routine Metallographic Examination of Commercial Magnesium Alloys. Published in ASTM BULLETIN, No. 129, August, 1944, p. 35. Discussion, p. 44.

Gibson, Kasson S.
Spectrophotometers, 725.

Gilkey, H. J.
The Data on Darex AEA. Appendix, Report of Working Committee of Committee C-1, 300.
Report of Working Committee on Additions, Committee C-1 on Cement, 299.

Glover, Stanton
Use of Synthetic Rubber in Footwear. Summary of Proceedings of the Cincinnati Spring Meeting—Symposium on the Applications of Synthetic Rubbers, 1095.

Gould, Louis P.
Cellular Rubbers. Summary of Proceedings of the Cincinnati Spring Meeting—Symposium on the Applications of Synthetic Rubbers, 1095.

Greenall, C. H.
Report of Committee B-5 on Copper and Copper Alloys, Cast and Wrought, 243.

Greenberg, S. A.
Report of Joint Committee on Filler Metal, 216.

Greenfield, Eugene W.
Discussion published in ASTM BULLETIN, No. 129, August, 1944, p. 34.

Grinsfelder, Henry
Fatigue Tests on Compressed and Impregnated Laminated Wood. Published in ASTM BULLETIN, No. 129, August, 1944, p. 31. Discussion, p. 34.
Discussion, 1016.

Grotlisch, V. E.
Report of Committee D-17 on Naval Stores, 492.

H

Hague, John L.
Colorimetric Analysis and Beer's Law, 712.

Hall, R. E.
Report of Committee D-19 on Water for Industrial Uses, 500.
Treatment of Various Types of Waters for Operating Pressures Above 400 psi., 1069.

Hanna, W. C.
Discussion, 802.

Harnden, G. H.
Report of Committee D-6 on Paper and Paper Products, 411.

Harvey, Dean.
Annual Report of the Executive Committee, 39.
The Art of Being a Materials Engineer. Annual Address by the President, 30.
Report of Committee B-4 on Electrical-Heating, Electrical-Resistance and Electric-Furnace Alloys, 240.

Heath, R. L.
Discussion published in ASTM BULLETIN, No. 129, August, 1944, p. 43.

Hecht, Max.
Report of Committee D-19 on Water for Industrial Uses, 500.

Herndon, L. K.
Report of Committee C-7 on Lime, 317.

Hess, R. E.
Report of Committee E-8 on Nomenclature and Definitions, 531.
Report of Committee E-10 on Standards, 533.
Report of Sectional Committee C59 on Electrical Insulating Materials, 457.
Report of Sectional Committee Z11 on Petroleum Products and Lubricants, 398.

Hettinger, E. L.
Discussion, 1007.

Heyer, Robert H.
Factors Affecting Hardness Relationships in the Range 50 to 250 Brinell, 1027. Discussion, 1048.

Hintermaier, John C.
Factors Influencing the Breaking Strength of Army and Navy Fabrics, 916.

Hocker, C. D.
Report of Committee A-5 on Corrosion of Iron and Steel, 87.

Hogentogler, C. A.
Report of Committee D-18 on Soils for Engineering Purposes, 497.

Holmes, J. A.
Classification of Feedwater for Boilers Operating Between 100–400 psi., 1078.
Discussion, 1093.

Hornibrook, F. B.
Discussion, 831, 835.

Hostetter, J. C.
Report of Committee C-14 on Glass and Glass Products, 354.

Howell, F. M.
Discussion, 1047.

Hubbard, Prévost.
Report of Committee D-4 on Road and Paving Materials, 401.
Report of Committee D-8 on Bituminous Waterproofing and Roofing Materials, 417.

I

Iliff, J. W.
Measurement of Fading Resistance of Camouflage Type Finishes by Accelerated Weathering, 905.

J

Jackson, F. H.
Report of Committee C-9 on Concrete and Concrete Aggregates, 336.

Jemal, Emile J.
Quantitative Spectrographic Analysis of Copper Alloys. Published in ASTM BULLETIN, No. 129, August, 1944, p. 45. Discussion, p. 52.

Joyce, C. M.
Discussion, 1082.

Juve, A. E.
The Processing Characteristics of the Synthetic Rubbers and Their Use in the Manufacture of Extruded Products. Summary of Proceedings of the Cincinnati Spring Meeting—Symposium on the Applications of Synthetic Rubbers, 1095.

Juve, Walter H.
Hard Rubber Products from Synthetic Rubbers. Summary of Proceedings of the Cincinnati Spring Meeting—Symposium on the Applications of Synthetic Rubbers, 1095.

K

Kendall, E. H.
Report of Committee B-1 on Copper and Copper Alloy Wires for Electrical Conductors, 218.

Kennedy, Henry L.
Entrained Air—Its Effect on the Constituents of Portland Cement Concrete, 821. Discussion, 832, 838.

Kennedy, R. E.
Discussion, 803.

Kenyon, Reid L.
Discussion, 1048.

Kerr, H. J.
Report of Joint Research Committee on Effect of Temperature on the Properties of Metals, 159.

Kester, B. E.
Discussion, 788.

Kies, J. A.
Short-Time Tests of Solders and Soldered Joints, 691.

Kirklin, W. A.
Report of Committee D-17 on Naval Stores, 492.

Kirmser, Philip G.
The Effect of Discontinuities on the Natural Frequency of Beams, 897.

L

Lang, F. C.
Discussion, 834.

Leavitt, H. W.
Discussion, 852.
Discussion published in ASTM BULLETIN, No. 130, October, 1944, 45.

Lundell, G. E. F.
Symposium on Analytical Colorimetry and Photometry—Opening Remarks, 709.
Report of Committee E-3 on Chemical Analysis of Metals, 521.

Lysaght, Vincent E.
Discussion, 992.
Discussion, 1046.

M

Maassen, G. C.
The Physical Properties of the Synthetic Rubbers. Summary of Proceedings of the Cincinnati Spring Meeting—Symposium on the Applications of Synthetic Rubbers, 1095.

MacKenzie, J. T.
Report of Committee A-3 on Cast Iron, 85.

Maguire, John J.
Discussion, 1092.

Markwardt, L. J.
Report of Committee D-7 on Timber, 415.

Martin, Wayne
Discussion, 637.

Masters, W. C.
Report of Committee A-2 on Wrought Iron, 83.

Maupin, Arthur R.
Discussion, 707.

McAdam, D. J.
The Technical Cohesive Strength of Some Steels and Light Alloys at Low Temperatures, 593. Discussion, 624.

McBurney, J. W.
Report of Committee C-12 on Mortars for Unit Masonry, 352.

McKay, R. J.
Report of Committee B-8 on Electrodeposited Metallic Coatings, 278.

Mears, R. B.
An Alternate Immersion Test for Aluminum-Copper Alloys, 639.

Mebs, R. W.
The Technical Cohesive Strength of Some Steels and Light Alloys at Low Temperatures, 593.

Mellon, M. G.
The Chemistry in Colorimetry, 733.

Meyer, L. W. A.
Report of Committee D-20 on Plastics, 505.

Miller, James A.
Discussion, 683.

Miller, Lewis B.
The Use of Selected Waters in Pulp and Paper Manufacture, 1061.
Discussion, 1082, 1087.

Mochel, N. L.
Report of Committee A-1 on Steel, 63.
Report of Joint Research Committee on Effect of Temperature on the Properties of Metals, 159.
Summary of Proceedings of Round-Table Discussion on Centrifugal Castings, 779.

Moore, H. F.
Third Progress Report on the Effect of Size of Specimen on Fatigue Strength of Three Types of Steel. Appendix, Report of Research Committee on Fatigue of Metals, 137. Discussion, 158.
Report of the Research Committee on Fatigue of Metals, 136.
Discussion, 624.

Morkovin, D.
Third Progress Report on the Effect of Size of Specimen on Fatigue Strength of Three Types of Steel. Appendix, Report of Research Committee on Fatigue of Metals, 137.

N

Nason, H. K.
Impact Testing of Plastics—II. Factors Which Influence the Energy Absorbed by the Specimen, 993. Discussion, 1007.
Discussion, 967.

Navias, Louis.
Report of Committee C-14 on Glass and Glass Products, 354.

Newell, H. D.
Report of Committee A-10 on Iron-Chromium, Iron-Chromium-Nickel and Related Alloys, 126.

O

Olt, T. F.
Cooperative Study of Effect of Rate of Strain on the Tensile Properties of Stainless Sheets, Report of Subcommittee V on Mechanical Tests, Committee A-10, 133.

P

Painter, R. J.
Report of Committee A-1 on Steel, 63.

Parsons, D. E.
Report of Committee C-15 on Manufactured Masonry Units, 356.

Paul, M. Rea
Report of Committee D-1 on Paint, Varnish, Lacquer, and Related Products, 362.

Pearson, J. C.
Volumetric Method for Determining the Air Content of Freshly Mixed Concrete. Appendix, Report of Committee C-9, 343.
Discussion published in ASTM BULLETIN, No. 130, Cctober, 1944, p. 43.

Peterson, R. E.
Discussion, 156.

Phelps, S. M.
Report of Committee C-8 on Refractories, 333.

Plummer, H. C.
Report of Committee C-12 on Mortars for Unit Masonry, 352.

Pratt, Horace A.
A Comparison of Results of Sieving Procedures in Soundness Tests on Maine Sands, 806.
Discussion, 852.

Pray, H. A.
Report of Subcommittee II, Committee B-8 on Performance Tests, 280.

Price, Walter H.
Precision Indices for Compression Tests of Companion Concrete Cylinders, 839. Discussion, 875.
Discussion published in ASTM BULLETIN, No. 131, December, 1944, p. 20.

R

Rawdon, H. S.
Discussion, 682.

Reich, W. A.
Report of Committee B-9 on Metal Powders and Metal Powder Products, 292.

Reid, L. S.
Report of Committee D-6 on Paper and Paper Products, 411.

Reinhard, C. E.
Report of Subcommittee VIII, Committee A-5, on Field Tests of Metallic Coatings, 92.

Reynolds, A. H.
Discussion, 663.
Discussion, 1087.

Robertson, J. A.
Report of Special Subcommittee on Use of the Autoclave for Testing Lime, Committee C-7 on Lime, 320.

Roeser, W. F.
Short-Time Tests of Solders and Soldered Joints, 691. Discussion, 707.

Rogers, A. T.
Discussion, 832.

Rose, C. H.
Report of Committee D-1 on Paint, Varnish, Lacquer, and Related Products, 362.

Rowe, H. J.
Report of Committee B-7 on Light Metals and Alloys, Cast and Wrought, 266.

Ruehle, A. E.
Filter Photometers, 718.

S

Sample, C. H.
Report of Committee B-8 on Electrodeposited Metallic Coatings, 278.

Sanford, R. L.
Report of Committee A-6 on Magnetic Properties, 114.

Sanger, M. J.
The Use of Synthetic Rubbers in Molded Products. Summary of Proceedings of the Cincinnati Spring Meeting—Symposium on the Applications of Synthetic Rubbers, 1095.

Schatzel, R. A.
Synthetic Rubbers in the Wire and Cable Industry. Summary of Proceedings of the Cincinnati Spring Meeting—Symposium on the Applications of Synthetic Rubbers, 1095.

Schrenk, Hermann von.
Report of Committee D-7 on Timber, 415.

Schroeder, W. C.
Introduction to Round-Table Discussion on Organizing the Classification of Industrial Waters, 1051. Discussion, 1094.

Schwartz, H. A.
Report of Committee A-7 on Malleable-Iron Castings, 124.

Schwartz, R. T.
Discussion, 967.

Scribner, B. F.
Report of Committee E-2 on Spectrographic Analysis, 519.
Discussion published in ASTM BULLETIN, No. 129, August, 1944, p. 52.

Selvig, W. A.
Report of Committee D-5 on Coal and Coke, 406.

Sheen, R. T.
Discussion, 1084.

Simmons, W.
Study of Effects of Variables on the Creep Resistance of Steels. Appendix I, Report of Joint Research Committee on Effect of Temperature on the Properties of Metals, 161.

Singleton, W. F.
The Interpretation of Visual Rusting Standards, 910.

Smith, A. J.
Evolution of Test Specimen for Non-Ferrous Castings, 625. Discussion, 638.

Smith, B. M.
Report on Round-Robin Core Loss Testing at High Flux Densities, Committee A-6, 120.

Smith, E. K.
Report of Committee A-7 on Malleable-Iron Castings, 124.

Smith, Harold DeWitt
Textile Fibers—An Engineering Approach to Their Properties and Utilization. Nineteenth Edgar Marburg Lecture, 543.

Smith, H. E.
Report of Committee D-1 on Paint, Varnish, Lacquer, and Related Products, 362.

Smith, P. J.
Report of Committee E-1 on Methods of Testing, 515.

Speller, Frank N.
Discussion, 1086.

Spooner, Thomas.
Report of Committee A-6 on Magnetic Properties, 114.

Stadtfeld, Nicolaas T. F.
Discussion, 802, 819.

Staley, H. R.
Report of Special Subcommittee on Use of the Autoclave for Testing Lime, Committee C-7 on Lime, 320.
Discussion, 789.

Stanton, Thomas E.
Tests Comparing the Modulus of Elasticity of Portland Cement Concrete as Determined by the Dynamic (Sonic) and Compression (Secant at 1000 psi.) Methods. Published in ASTM BULLETIN, No. 131, December, 1944, p. 17. Discussion, p. 20.

Stenger, V. A.
Colorimetric Methods for the Analysis of Magnesium-Base Alloys, 754.

Stericker, William
Discussion, 1082.

Stillman, J. W.
Bibliography of Photoelectric Spectrophotometric Methods of Analysis for Inorganic Ions, 740.

Stock, C. R.
Discussion, 1007.

Strauss, Jerome.
Report of Committee A-10 on Iron-Chromium, Iron-Chromium-Nickel and Related Alloys, 126.

Stumm, Joseph J.
Colorimetric Determination of Silicon in Aluminum Alloys, 749.

Sullivan, J. D.
Report of Committee C-8 on Refractories, 333.

Swartz, C. E.
Report of Committee B-2 on Non-Ferrous Metals and Alloys, 220.

Swayze, M. A.
Discussion, 802, 832.

T

Telfair, David
Impact Testing of Plastics—II. Factors Which Influence the Energy Absorbed by the Specimen, 993. Discussion, 1007.
Discussion, 967.

Templin, R. L.
Discussion, 685.

Thomas, Arba
Colorimetric Methods for the Analysis of Ferrous Alloys, 769.

Thomas, Ray.
Report of Committee C-16 on Thermal Insulating Materials, 358.

Toeplitz, W. R.
Report of Committee B-9 on Metal Powders and Metal Powder Products, 292.

Torrance, P. M.
Synthetic Rubber Tires and Inner Tubes. Summary of Proceedings of the Cincinnati Spring Meeting—Symposium on the Applications of Synthetic Rubbers, 1095.

Tour, Sam
Report of Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys, 222.
Report of Committee B-7 on Light Metals and Alloys, Cast and Wrought, 266.
Discussion, 637, 663.

Townsend, J. R.
Report of Committee B-6 on Die-Cast Metals and Alloys, 261.

Tracy, A. W.
Report of Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys, 222.

Tremper, Bailey
The Measurement of Concrete Strength by Embedded Pull-Out Bars, 880.

Trevithick, H. P.
Report of Committee D-12 on Soaps and Other Detergents, 470.

Trostel, L. J.
Report of Committee C-8 on Refractories, 333.

U

Ullman, Eric
Factors Influencing the Breaking Strength of Army and Navy Fabrics, 916.

V

Van Zile, B. S.
Report of Committee D-12 on Soaps and Other Detergents, 470.

Vassar, H. S.
Report of Committee E-10 on Standards, 533.

von Bergen, Werner
Factors Influencing the Breaking Strength of Army and Navy Fabrics, 916.

Voss, W. C.
Report of Committee C-7 on Lime, 317.

W

Waldron, L. J.
Basic Requirements in the Standardization of the Salt Spray Corrosion Test, 654. Discussion, 663.

Walker, Stanton.
Report of Committee C-9 on Concrete and Concrete Aggregates, 336.

Walton, C. J.
An Alternate Immersion Test for Aluminum-Copper Alloys, 639.

Warren, G. E.
Report of Committee C-1 on Cement, 294.

Warwick, C. L.
Annual Report of the Executive Committee, 39.

Watkins, E.
Flow of Thermosetting Plastics at Elevated Temperatures, 1009.

Wehmer, Fred J.
Synthetic Rubber Adhesives. Summary of Proceedings of the Cincinnati Spring Meeting—Symposium on the Applications of Synthetic Rubbers, 1095.

Weiner, Albert
The Reaction of Vinsol Resin as It Affects the Air Entrainment of Portland-Cement Concrete. Published in ASTM BULLETIN, No. 130, October, 1944, p. 41. Discussion, p. 46.

Weiss, J. M.
Report of Committee D-8 on Bituminous Waterproofing and Roofing Materials, 417.
Report of Committee D-16 on Industrial Aromatic Hydrocarbons, 490.

Wells, L. S.
Report of Special Subcommittee on Use of the Autoclave for Testing Lime, Committee C-7 on Lime, 320.

Welter, Georges
Micro-Deformation Under Tension and Compression Loads of Thin Aluminum Alloy Sheets for Aircraft Construction, 665. Discussion, 687.

Werley, G. L.
Report of Committee B-6 on Die-Cast Metals and Alloys, 261.

Whirl, S. F.
Discussion, 1089.

Whitcomb, W. H.
Report of Committee D-13 on Textile Materials, 474.

White, W. L.
Belting and Hose Made from Synthetic Rubber. Summary of Proceedings of the Cincinnati Spring Meeting—Symposium on the Applications of Synthetic Rubbers, 1095.

Whittemore, J. W.
Report of Committee C-15 on Manufactured Masonry Units, 356.

Wilson, Bruce L.
Characteristics of the Tucherman Strain Gage, 1017.

Wing, S. P.
Precision Indices for Compression Tests of Companion Concrete Cylinders, 839. Discussion, 875.
Discussion, 803.

Witte, L. P.
Discussion published in ASTM BULLETIN, No. 131, December, 1944, p. 20.

Wolfe, R. A.
Quantitative Spectrographic Analysis of Copper Alloys. Published in ASTM BULLETIN, No. 129, August, 1944, p. 45. Discussion, p. 52.

Worley, W. J.
Short-Time Static Tests and Creep Tests of a Paper Laminated Plastic, 949. Discussion, 968.

Wuerpel, C. E.
Report on Cooperative Studies of Proposed. Method of Test for Air Content of Portland-Cement Mortar. Appendix I, Report of Committee C-1, 306.
The Reaction of Vinsol Resin as It Affects the Air Entrainment of Portland-Cement Concrete. Published in ASTM BULLETIN, No. 130, October, 1944, p. 41. Discussion, p. 43.
Discussion, 831, 832, 833, 834.

Wyman, L. L.
Report of Committee E-4 on Metallography, 523.

Y

Young, E. R.
Report of Committee A-3 on Cast Iron, 85.

Z

Zinzow, W. A.
Report of Committee D-9 on Electrical Insulating Materials, 422.

Zischkau, C.
Colorimetric Methods for the Analysis of Copper-Base Alloys and Refined Lead, 762.